AN EXPERT SYSTEM DEVELOPMENT USING TURBO PROLOG FOR DESIGN OF HIGHWAY INTERSECTIONS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

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to the

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

MARCH, 1989

dedicated to

my

PARENTS

CERTIFICATE

This is to certify that the thesis entitled, "AN EXPERT SYSTEM DEVELOPMENT USING TURBO PROLOG FOR DESIGN OF HIGHWAY INTERSECTIONS", submitted by Mr.KUNAM HARISCHANDRA REDDY in partial fulfilment of the requirements for the award of the degree of Master of Technology of the Indian Institute of Technology Kanpur, is a record of bonafide work carried out by him under my supervision and guidance. The work embodied in this thesis has not been submitted elsewhere for a degree.

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ACKNOWLEDGEMENT

I am very much thankful to Prof. Palaniswamy, who suggested such a new and advanced topic, given proper suggestions and helped me to complete it successfully. I am highly indebted to him for his special interest in my work.

My sincere regards are to Prof. Marwah, who encouraged me throughout the period of my course work.

I am grateful to Jayakumar who helped me in many ways throughout this work.

Thanks are due to Sathi Kumar, Roy, Swaroop, Nishoo, Anchala, JacksN and Anji Reddy who helped at several stages during this work.

CONTENTS

PAGE NO.

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In this thesis it is aimed to develop expert system for atgrade intersection. Four types of intersections are considered as alternatives. They are simple intersection, signallized intersection, rotary type intersection and signallized rotary type intersection. The program is made highly user interactive. The user need not be highly knowledgeable about the problem. He will just have to answer the queries of the expert system and enter the required data. The program is aimed to take a decision on which type of intersection is eminently suitable for the given situation and to provide all the design details as well as performance characterestics for the suggested intersection. Regarding design details, it gives number of phases for signal and its cycle timings, shape and size of rotary, widths of approach roads, widths within the intersection, details for channellizing islands, sight distance specifications, lengths of speed change lanes and includes many other minor details as per the requirement of the problem on hand. Regarding performance characterestics, it gives capacity of the suggested intersection, average delay per vehicle at the intersection, queue lengths at the approaches of signallized and priority type simple intersections etc. The program has been executed for two actual field problems and consultation paradigms for both of them are incorporated in the report. Turbo Prolog is used as the programming language for the expert system development.

CHAPTER I

INTRODUCTION

1.1 General

People have always been fascinated by the prospect of intelligent artefacts. In earlier days the technology did not exist to make an intelligent machine. Even at the beginning of this century an intelligent machine was still considered to be a pipe-dream. But with the arrival of computers man-made intelligence became plausible. Seeing how readily computers could be used to solve problems that were too tedious for humans, speculation began as to whether they could also be used to solve problems that humans found too difficult. Speculation gave way to experiments and after another six years the artificial intelligence programs appeared. After that within a few years we have programs for playing chess, proving theorems of geometry, solving puzzles and brain teasers that up till then could only be done by man. Thus Artificial Intelligence was born. Expert Systems comes under applied artificial intelligence.

Transportation contributes to the economic, industrial, social and cultural development of any country. Among all modes of transportation, road transport is the most easily accessible mode available to people. The road network could alone serve the remotest villages of the country. Road transport has recorded a phenominal growth in the wake of all round national development in the country. Hence there is a need for upgrading the roads. Road intersections are a critical element of a road section. They are normally a major bottleneck for smooth flow of traffic and major

accidents take place on these spots. Studies in India and abroad have shown that as much as 25 to 33 percent of total accidents occur at intersections(Ref. 8). This exemplifies the need to have properly designed intersections both on rural sections of highways and roads in the urban areas. The general principles governing the design of intersections in both the rural and urban areas are the same. The basic difference lies in the design speeds, restriction on available land, restriction on sight distance available and the presence of larger volume of pedestrians and cyclists in urban areas.

1.2 Artificial Intelligence (AI)

Classical definition of AI is as follows.

"AI is the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characterestics we associate with intelligence in human behaviour, understanding language, learning, reasoning, solving problems and so on." (Ref. 11)

Thus AI is concerned with programming computers to perform tasks that are presently done better by humans, because they involve such higher mental processes as perpetual learning, memory organization and judgemental reasoning. Thus writing a program to perform complicated statistical calculations would not be seen as an AI activity, while writing a program to design experiments to test hypothesis would.

1.3 Expert Systems (ES)

These are also known as Knowledge Based Expert Systems (KBES) as the central component of them is a knowledge base.

Expert Systems can be defined as "very highly interactive computer programs incorporating judgement, rules of thumb, intuition and other expertise to provide knowledgeable advice about a variety of tasks." (Ref. 6)

1.4 Difference Between Traditional Programs and Expert Systems (Ref. 6 & Ref. 4)

1. Expert systems are highly interactive.
2. Expert systems are knowledge intensive programs and expert knowledge is divided into many seperate rules.
3. Expert systems are highly helpful to solve unstructured problems and where no formal procedure exists but formal reasoning is necessary.
4. Expert systems to some extent mimic the decision making and reasoning process of human experts. They can provide advice, answer questions and justify their conclusions.
5. Expert systems uses heuristics to solve problems.

1.5 Language Environment for Expert Systems

Expert systems can be developed in any language environment. But this task is very difficult to perform with procedural languages such as FORTRAN, BASIC, Pascal etc. Expert systems can be developed with object-oriented languages such as Prolog and LISP. The reason behind is given in the following paragraphs.

To use a procedural language an algorithm (or procedure) must first be defined to solve the problem at hand. Then a program has to be structured using the procedural language to implement the procedure. The program can execute the same procedure a number of times with different input data. The program will be faster and

more reliable than a human being in solving any problem requiring the use of that procedure, but the program will be limited to problems involving that single procedure.

Developing programs with object-oriented languages is absolutely different. They use no procedures and essentially no program. They use only data about objects and their relationships. They also emphasize symbolic processing. When the user defines a goal (a problem or objective), the computer must find both the procedure and solution. They are a collection of data or facts and the relationships among these facts. In other words, they are database. These languages permit the user to do things with his computer that could only be done inefficiently or not at all with other languages. However they are very inefficient for numerical or string processing involving known procedures.

LISP and Prolog are the best-known object-oriented languages. Both of them have strong points and weak points in their favour. LISP is clearly a more mature language than is Proog, simply because it has been around for a longer period and has had more time to become understood and established. However, Prolog continues to gain adherents. Both languages use techniques different from those of conventional programming languages. Prolog offers more functionality to program developers but gives up some of LISP's flexibility in the process. This suggests that applications can be developed more rapidly in Prolog than LISP. On the other hand LISP is easier to read, write and change than is Prolog code. Prolog tends to be more cryptic and its back-chaining reasoning methodology makes it more difficult to understand how a program

works. Prolog also requires more advance work before actually writing a program, imposing a form of discipline on the system developer. For this reason LISP is suited to an unstructured approach. LISP appears to be more suitable for general purpose programs than Prolog. Various versions of Prolog are Arity Prolog, Micro Prolog, Prolog-1 and Prolog-2, Prolog-86 and Turbo Prolog. Turbo Prolog is chosen as programming language for present work. (Ref. 4 and Ref. 5)

1.6 Components of an Expert System

An expert system has two primary components: the knowledge base and the inference engine as shown in Fig. 1.1. (Ref. 4 & Ref. 22)

A knowledge base is data or knowledge used to make decisions. A knowledge base contains rules and facts about the domain. Such a rule based representation allows an expert system to approach a problem in a way similar to a human expert.

Let us consider one rule

IF the number of legs of an intersection (Nlegs) is more than or equal to four,

AND total volume at the intersection (Total_volume) is less than or equal to 3500,

AND total volume at the intersection (Total_volume) is more than 2000,

AND right turns at that intersection (Right_turns) are more than 30% of total volume,

THEN provide a rotary.

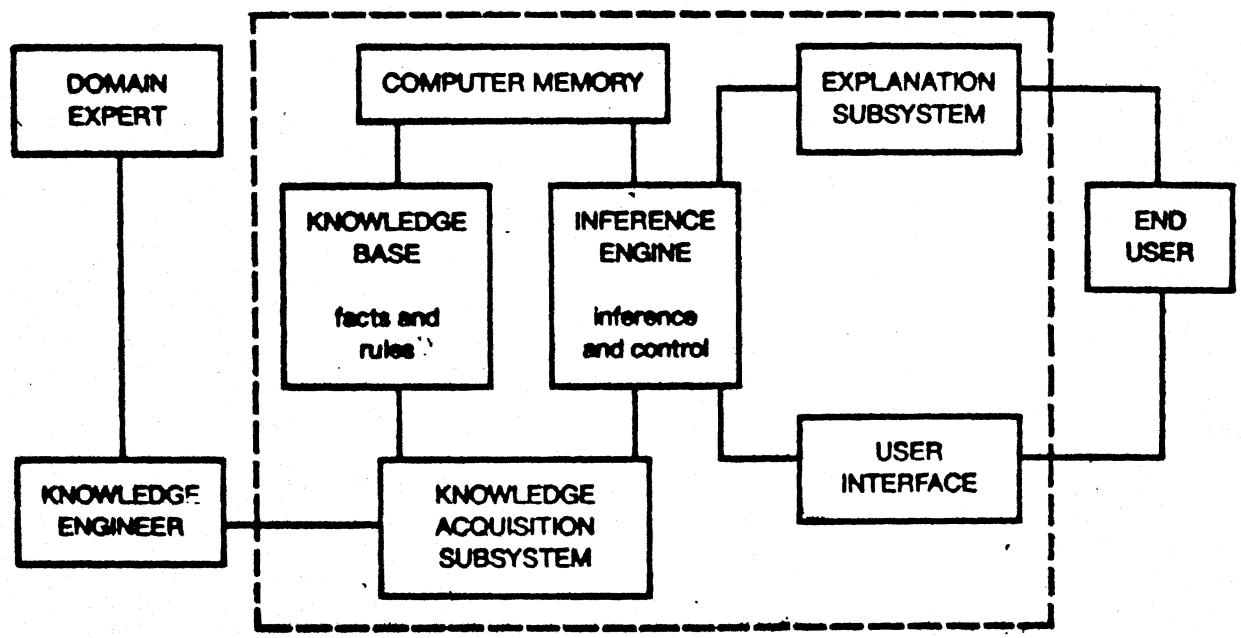

Fig 1.1 Components of an Expert System

In Prolog such a representaion can be expressed as

```
hypothesis (Nlegs,Total,Right_turns,Nature) :-

     Nlegs >= 4,
     Total_volume <= 3500,
     Total_volume >  2000,
     Right_turns  >  0.3*Total_volume,
     Nature = 'rotary'.
```

The knowledge base consists of two parts: the working memory and the rule base. The rule base consists of facts that are compiled as part of the problem. They do not change during a particular consultation. This type of rule base corresponds to static database (the above mentioned rule is a part of the static database as it is common to any type of problem). Second part of the knowledge base is the working memory. It consists of the facts relative to a particular consultation. The working memory corresponds to dynamic database. At the begining the working memory/dynamic database is empty. As the consultation progresses, the inference engine (discussed below) uses facts and rules in the rule base, in conjunction with the user input, to add facts to the working memory (such as Nature = rotary will be saved in dynamic databse).

The inference engine has two function: Inference and Control. Inference is the basic formal reasoning process. It involves matching and unification, it uses facts that are known to derive new facts by means of rules (as mentioned above after knowing Nlegs, Total_volume, Right_turns, Nature is bound to rotary). The control function determines the order in which the rules are tested and what happens when a rule succeeds or fails. The inference takes the facts that it knows are true from the static and dynamic databases and uses these to test the rules in the

database through the process of unification (once Nature is bound to rotary, inference engine takes it as a fact and uses it in proving other rules). When a rule succeeds, the conclusion of the rule is added to the working memory (such as Nature = rotary).

1.7 Factors Affecting Intersection Design (Ref. 8)

Design of safe intersection depends on many factors. The major factors can be classified as under.

a. Human factors

1. Driving habits
2. Ability to make decisions
3. Driver expectancy
4. Decision and reaction time
5. Conformance to natural paths of movement
6. Pedestrian use and habits

b. Traffic considerations

1. Design and actual capacities
2. Design_hour turning movements
3. Size and operating characteristics of vehicle
4. Variety of movement
   (diverging, merging, weaving and crossing)
5. Vehicle speeds
6. Transit involvment
7. Accident experience

c. Physical elements

1. Character and use of abutting property
2. Vertical alignments at the intersection
3. Sight distance

4. Angle of the intersection
5. Conflict area
6. Speed change lanes
7. Geometric features
8. Traffic control devices
9. Lighting equipment
10. Safety features

d. Economic factors

1. Cost of improvements
2. Energy consumption
3. Effects of controlling or limiting right-of-way on abutting residential or commercial properties where channellization restricts or prohibits vehicular movements.

1.8 Objective of the Thesis

The aim of the current work is to develop a software package (Expert System) for an at grade intersection design. The package is aimed in such a way that it gives complete details regarding the design of an at grade intersection. The person who runs the program will just have to answer the questions it asks and enter the required data it asks. The various types of intersections that are considered are

i. Simple intersection
ii. Signallized intersection
iii. Rotary type intersection
iv. Signallized rotary

With reference to the data entered, the program has to take a decision regarding the nature of the intersection that is to be

provided. It should also give the specifications for all other details such as signal timings, rotary details, channelizing islands, sight distance specifications etc.

1.9 Thesis Organisation

Other than the Introduction Chapter, this report consists of four chapters. Various design principles and design standards for designing intersections are detailed in Chapter II. Usual steps to be performed in building an expert system are outlined in Chapter III. The results of the program for a few problems and discussion over them are mentioned in Chapter IV. Chapter V consists of conclusions to the present work, limitations of the present work and suggestions for future work.

CHAPTER II

INTERSECTION DESIGN - AN OVERVIEW

2.1 General

The previous work that has been done on Intersection Design is reviewed in this Chapter. Various design principles and standards for design of different elements are outlined. It is to be assumed that, they are outlined according to Ref. 8 unless otherwise mentioned against any article.

2.2 Design Data Required for Intersection Design

In order to be able to properly design an intersection and give consideration to factors affecting design, the following essential data must be collected.

a. An index/location plan in the scale of about 1:10,000 to 1:20,000 showing the juction under consideration.

b. A base plan of the junction site in the scale of 1:500.

c. Peak hour design traffic data.

d. Other relevant details such as the feasibility of providing proper drainage and lighting system at the intersection etc.

Among all these, the third one is most important. Without this data, the problem virtually remains undefined. The design hour peak traffic data should invariably give its compositional and directional breakup. A sample proforma which is to be used for the purpose of reporting the compositional and directional breakup and computing the volume in PCUs (Passenger Car Units) for one leg of a four legged intersection is shown in Table 2.1.

Table 2.1

Proforma for Collecting Intersection Traffic Data

Design traffic peak hour from _______hrs. to _______hrs.

Name & Location of intersection ______________________________

Traffic entering from					LEG A					
into			LEG B			LEG C			LEG D	
Sl. No.	Type	Nos.	PCU equiv.	Total PCU	Nos.	PCU equiv.	Total PCU	Nos.	PCU equiv.	Total PCU
F A S T 1.	Passenger cars, tempos, auto rickshaws, tractors		1.ØØ			1.ØØ			1.ØØ	
2.	Motor cycles, Scooters		Ø.5Ø			Ø.5Ø			Ø.5Ø	
3.	Trucks, Buses Tractor trailer units		3.ØØ			3.ØØ			3.ØØ	
TOTAL FAST										
S 4.	Cycles		Ø.5Ø			Ø.5Ø			Ø.5Ø	
L 5.	Cycle rickshaws		1.5Ø			1.5Ø			1.5Ø	
O 6.	Horse drawn		4.ØØ			4.ØØ			4.ØØ	
W 7.	Bullock carts		8.ØØ			8.ØØ			8.ØØ	
TOTAL SLOW										
Pedestrians (nos.)										

F : FAST

S : SLOW

TF : TOTAL FAST

TS : TOTAL SLOW

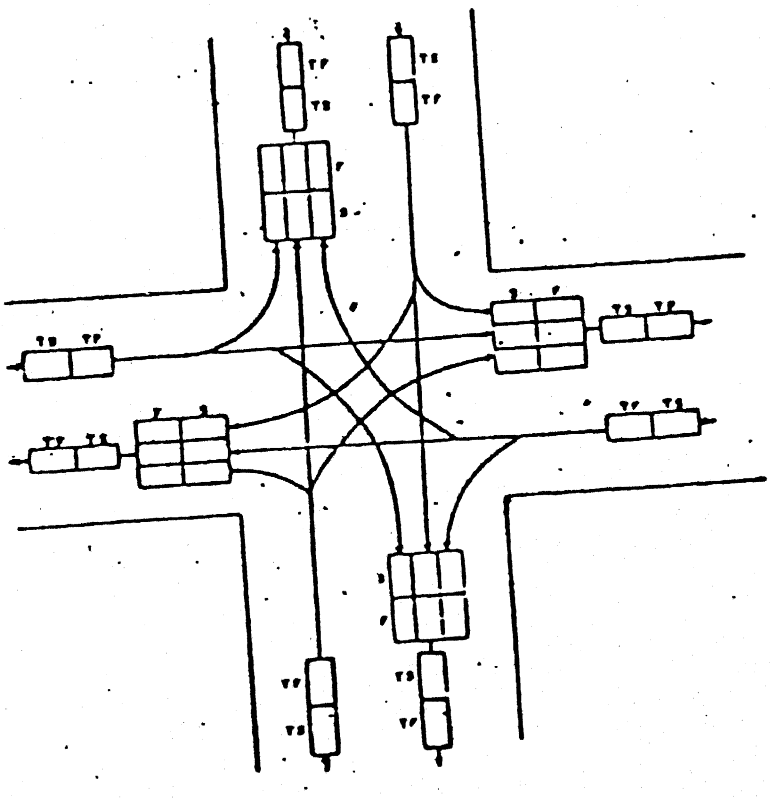

Fig 2.1 Peak Hour Traffic Flow Diagram

For converting vehicles into PCUs, equivalency factors given in Table 2.1 should be used. Such type of seperate sheets will be needed for the other legs of the intersection. The volume of the above traffic in terms of number of vehicles and in PCU should then be reflected in the diagram shown in the Fig. 2.1. If the number of legs in the intersection is 3 or more than 4, Table 2.1 and Fig. 2.1 should be suitably modified. For the design of intersections, traffic projections for a time horizon of 5 years should be considered.

2.3 Basic Design Principles

2.3.1 Uniformity and Simplicity

Intersections must be designed and operated for simplicity and uniformity. It must keep the capabilities and limitations of drivers, pedestrians, and vehicles using it in view. As such the design should be based on knowledge of what a driver will do rather than what he should do. Complex designs which requires complicating decision making by drivers should be avoided. Further, on an average trip route, all the intersections should be of uniform design standard. Some of the major design elements in which uniformity is required are design speed, intersection curves, intersection angles, vehicle turning paths, super structures, widths, shoulder width, speed-change lane lengths, channelizations, types of curves and type of signs and markings etc.

2.3.2 Minimisation of Conflict Points

The main objective of the intersection design is to minimise the number and severity of potential conflicts between the

vehicles using it. Wherever possible the points of potential conflicts should be seperated in space and time. Space separation can be by access control as channelizing islands and time speration can be by traffic signals or waiting lanes etc. Any location having merging, diverging or crossing manoeuvres of two vehicles is a potential conflict point. A 4-arm intersection has 32 potential conflict points. A 3-armed intersection has 9 potential conflict points. A 4-arm roundabout has 12 conflict points. The aim of the designer interested in safety is to reduce the potential conflict points and wherever possible to keep them as far apart as possible so that severity of accidents is less. This can be achieved in many ways. Some of the common methods used to reduce conflict points are as follows.

a. Converting a 4-armed intersection having 32 conflict points to a roundabout having only 12 conflict points.

b. Signallizing intersection. Introduction of a two phase signal reduce the conflict points at 4-armed intersection from 32 to 16.

c. Channelizing the differenct directions of traffic by selective use of channelizing islands and medians.

d. Changing priority of crossing by introducing the GIVE-WAY or STOP signs for traffic entering the junctions from minor road.

e. Staggering 4-armed junctions by flexing the two opposing a arms of the side road to create two T-junctions.

Care should be taken to see that whether they are feasible for that intersection from other points of consideration also.

2.3.3 Safety

The safety of a perticular design can best be assessed by studying the frequency with which types of accidents occur at particular type of intersection and its correlation with volume and type of traffic. Some of the measures which have proved to improve safety of intersections are as follows

a. In rural sections, by eliminating highly trafficked side road connections upto 30% reductions in accidents can be made.

b. By converting lightly trafficked cross road into properly designed staggered junction, 60% reductions in accidents is possible.

c. In urban areas control of access, proper lighting, street parkings and off development in the vicinity of intersection improves the safety considerably.

2.3.4 Alignment and Profile

In hilly and rolling terrain, site coditions governs the alignment and grade of the intersections, but the safety can be considerably improved by designing the intersection with modification in alignment and grades. As a general rule safety is best achieved when the intersecting roads meet at or nearly at right angles. Intersection on sharp curves should be avoided because the superelevation and widening of pavement complicates the intersection design. Combination of grade lines or substantial grade changes make vehicle control difficult and should be avoided at intersection. The profile of grade lines and cross sections on the intersection legs should be adjusted for a distance back from the intersection proper to provide a smooth

junction and proper drainage. Normally, the grade line of the major highway should be carried through the intersection, and that of the cross road should be adjusted to it. Transitions and required sight distances should be provided wherever necessary.

2.4 Intersection Design Elements

Junctions are to be designed having regard to the flows, speed, compostions, distributions and future growth of traffic. Some of the major design elements and important advances made through research in respect of these are detailed in the following paragraphs.

2.4.1 Design Speed

Three types of design speed are relevant for intersection design element.

a. Open highway or approach speeds.

b. Speeds at intersection for design of various intersection elements.

c. Transition speeds for design of speed change elements.

The approach speeds relevant to various types of terrain and roads are given in Tables 2.2 and 2.3 for rural areas and urban areas respectively.

2.4.2 Design Traffic Volumes

Intersections are normally designed for peak hour flows. Estimation of future traffic and its distribution at peak hours is done on the basis of past trends and by accounting for factors like new development of land, socio-economic changes etc. Where it is not possible to predict traffic for longer period,

Table 2.2

Design Speeds in Rural Areas

Sl. No.	Road classification	Design speed (kmph)							
		Plain terrain		Rolling terrain		Mountainous terrain		Steep terrain	
		Ruling design speed	Minimum design speed	Ruling design speed	Minimum design speed	Ruling design speed	Minimum design speed	Ruling design speed	Minimum design speed
1.	National and State highways	100	80	80	65	50	40	40	30
2.	Major district roads	80	65	65	50	40	30	30	20
3.	Other district roads	65	50	50	40	30	25	25	20
4.	Village roads	50	40	40	35	25	20	25	20

Table 2.3

Design Speeds in Urban Areas

Sl. No.	Road classification	Design speed (kmph)
1.	Arterial	80
2.	Sub-arterial	60
3.	Collection street	50
4.	Local street	30

intersection should be designed for stage development for design periods in steps of 5 years. Where peak hour flows are not available they may be assumed to be 10 to 15% of the daily flow. In urban areas the junction should be designed by total network flow analysis. In planning the networks, junction capacity should be kept in balance with that required on the road system between junctions.

2.4.3 Radii of Curves at Intersection

The radii of intersection curves depend on the turning characterestics of design vehicles, their numbers and the speed at which vehicles enter or exit the intersection area. Minimum design of curve is developed by plotting the path of the design vehicles on the sharpest turn and fitting curve or combination of curves to the path of inner rear wheels. Generally four types of curves are possible to fit in with the wheel paths of turning vehicles. They are

a. Simple circular curve

b. 3-centered compound curve with offsets

c. Simple curve with offset and taper

d. Transitional curves

The first step in design consists of study of the projected traffic data, the number and frequency of the larger units involved in turning movement and the effect of those large units on other traffic. If very large units are only occasional and they can turn with some encroachment on other traffic lanes and without disturbing traffic too much, it would be wasteful to design for the largest truck. However, the minimum design may

need some modification to permit turning of the largest occasional truck.

Indian Roads Congress(IRC) recogises three types of road design veicles namely single unit truck, semi-trailor and truck-trailer combination. Passenger cars are not considered as design veicles in rural areas. Nearly all intersection curves in rural areas should be designed for either single unit trucks/buses of 11/12metres length, or semi-trailer combinations of 16metres length or truck-trailer combination of 18metres length. On most rural highways semi-trailer combination would be used for design, whereas in non-arterial urban areas a single unit truck/bus can form the basis for design.

There are five common situations in design of intersections and each one has to be generally designed for the following conditions.

a. In rural section, single unit truck is preferred for intersection with local minor roads. Semi trailer design is preferred for major road.
b. In suburban arterial section, curves are designed for semi trailer with speed change lanes and channelization. Three centered compound curves are preferred.
c. In urban arterials and sub arterials, curves are designed for single unit truck.
d. In urban Central Business Districts (CBD), single unit truck stands as the basis for design of minimum curve radii with allowance for turning vehicles encroaching on other lanes.

e. In residential areas cars alone with encroachment of trucks into other lanes are used for designs.

In urban areas additional conditions like restriction on right of way widths, abutting developments, pedestrian crossings, parked vehicles and high cost of land govern the minimum radii at intersections. Lower operating speeds and frequent signal stops also reduce the requirement of intersection areas. Generally, the minimum turning radius for a vehicle governs the design.

The radii of different curves for given design vehicles and angle of vehicle turn recommended by IRC are shown in Table 2.4.

2.4.4 Width of Turning Lanes at Junction

Determination of widths of turning lanes of intersection is primarily based upon the type of vehicles using it, the length of lanes, the volume of traffic and once kerbs are provided the

Table 2.5

Width of Carriageways at Junctions

Design speed (kmph)	Single lane width (metres)	Single lane width with space to pass stationary vehicle (metres)	Two lane width for one or two way traffic (metres)
10	5.50	10.30	11.50
23	5.20	9.40	10.60
27	5.00	8.80	10.00
32	4.60	7.90	9.10
37	4.50	7.50	8.70
41	4.50	7.20	8.40
50	4.50	7.00	8.20
57	4.50	6.80	8.00
62	4.50	6.60	7.80
64	4.50	6.40	7.60
>64	4.50	6.00	7.30

Table 2.4

Radii of Curves for Different Design Vehicles
and Different Angle of Turns

Design Vehicle	Angle of turn	Radius of Simple curve	Radius of curve with taper	Radii of 3-centered compound curve
P	30	18.30	-	-
SU		30.50	-	-
WB-40		45.70	-	-
WB-50		61.00	-	-
P	45	15.20	-	-
SU		22.90	-	-
WB-40		36.60	-	-
WB-50		51.80	36.60	61.0-30.5-61.0
P	60	12.20	-	-
SU		18.30	-	-
WB-40		27.40	-	-
WB-50		-	28.96	61.0-22.0-61.0
P	75	10.70	7.62	30.5- 7.6-30.5
SU		16.80	13.72	36.6-13.7-36.6
WB-40		25.90	18.28	36.6-13.7-36.6
WB-50		-	19.81	45.7-15.2-45.7
P	90	9.20	6.10	30.5- 6.1-30.5
SU		15.20	12.19	36.6-12.2-36.6
WB-40		-	13.72	36.6-12.2-36.6
WB-50		-	18.29	54.9-18.3-54.9
P	105	-	6.10	30.5- 6.1-30.5
SU		-	10.66	30.5-10.7-30.5
WB-40		-	12.19	30.5-10.7-30.5
WB-50		-	16.76	54.9-13.7-54.9
P	120	-	6.10	30.5- 6.1-30.5
SU		-	9.14	30.5- 9.1-30.5
WB-40		-	10.67	36.6- 9.1-36.6
WB-50		-	13.72	54.9-12.2-54.9
P	135	-	6.10	30.5- 6.1-30.5
SU		-	9.14	30.5- 9.1-30.5
WB-40		-	9.14	36.6- 9.1-36.6
WB-50		-	12.19	48.8-10.7-48.8
P	150	-	5.49	20.9- 5.9-20.9
SU		-	9.14	30.5- 9.1-30.5
WB-40		-	9.14	30.5- 9.1-30.5
WB-50		-	10.67	48.8-10.7-48.8
P	180	-	4.57	15.2- 4.6-15.2
SU		-	9.14	30.5- 9.1-30.5
WB-40		-	6.00	36.6- 6.1-36.6
WB-50		-	7.62	39.6- 7.6-39.6

P - Passenger Car
SU - Single Unit Truck
WB-40 - Semi Trailer
WB-50 - Truck Trailer

necessity to pass a stalled vehicle. Table 2.5 gives the recommended widths of turning lanes.

2.4.5 Auxillary Lanes

Three types of auxillary lanes are to be provided at intersections. These are storage lanes, acceleration laes and deceleration lanes. Provision of these increases the capacity of intersection and improves safety. The length of these lanes depends on the speed of traffic, the volume of traffic on major road and the volume of traffic entering or leaving the side road.

Storage lanes are generally more important in urban areas where volume of right turning traffic is high. Normal design procedure provides for storage length based on 1.5 times the average number of vehicles that would store in turning at peak hour. At the same time the concurrent through lane storage must also be kept in view, as it may happen that entry to turning lane may become inaccessible due to queed vehicles in through lane.

Accelerated lanes and deceleration lanes (speed change lanes) are more important in rural areas. In urban areas such lanes are rarely required. An acceleration lane should be designed so that vehicles turning left from the minor road may join the traffic flow on the major road at approximately the same speed as that of the near side lane traffic in the major road. Acceleration lanes also improves capacity by enabling the use of short traffic gaps and by providing storage space for traffic waiting to merge when large traffic gaps occur. Recommended lengths of acceleration lanes for different main road design speeds are given in Table 2.6. In different conditions, sub-standard lengths may have to be

accepted but they should never be less than half of these values.

Deceleration lanes are of greater value than acceleration lanes because the driver of a vehicle leaving the highway has no choice but to slow down any following vehicle on the through lane if a deceleration lane is not provided. They are needed on the near side for left turning traffic and onto the right turn lane where provision made is for right turning traffic. The length of near side deceleration lanes should be sufficient for vehicles to slow down from the average speed of traffic in the near side lane to the speed necessary for negotiating the curve at the end of it. The length of right-turn deceleration lanes should be sufficient for vehicles to slow down to a stop from the average speed of vehicles in the off side lane. Recommended lengths for both these lanes are shown in Table 2.6. Here also sub-standard lengths may be provided when the situation needs but they should not be less than half the recommended lengths.

Table 2.6

Length of Speed Change Lanes

Design speed (kmph)	Visibility distance at junctions (metres)	Acceleration lane length incl. nose (metres)	Nearside lane length incl. nose (metres)	Right turn dec. lane length incl. taper (metres)
120	230	400	210	200
100	210	280	160	160
80	180	210	130	130
60	140	140	110	110

2.4.6 Superelevation & Drainage of Intersection

Where the turning slip lanes are provided for higher speed

operation at intersection, they should be superelevated for the appropriate speed. As in intersection design the actual curves are of limited radii and length, it is difficult to provide the required superelevation without causing abrupt crozz-slope change which could be dangerous. In practice therefore lower rates of superelevation are often accepted at intersection to maintain riding comfort, appearance and to effect a balance in design. In the intersection area normally the pavement cross-slopes should be carried through to the turning lanes as well to avoid creation of drainage problem. Extreme care has to be exercised to check the drainage of the entire intersection area. Wherever necessary, drainage inlets should be designed and so located as to minimise the spread of water on traffic lanes and eliminate stagnant pools in the intersection area.

2.4.7 Visibility of Junction

A major factor in safety at intersections is the sight distance. There are two considerations which are important to the driver as he approaches an intersection. First one is the overall visibility of the junction layout. Layout of intersection should be such that it can be grasped at first glance, being as simple as possible so that no confusion is created in the mind of the approaching drivers. Second important requirement to safely negotiate an intersection is the sight triangle visibility. After a driver becomes aware of approaching junction, he must be able to observe the speed and direction of approaching traffic to his right and left. If a vehicle is approaching, he should be able to make a safe stop prior to reaching the intersection. The driver must be able to see sufficient distance along the cross road to allow judge if he can make a crossing by suitably adjusting

the speed. For minimum sight triangle condition, IRC identifies two specific cases. They are

a. "Uncontrolled intersections" where the intersecting roads are of more or less equal importance and there is no established priority.

b. "Priority intersections" like minor road intersections where one road takes virtual predominance over the other. Traffic on mior road may be controlled by GIVE-WAY or STOP signs/road markings.

On uncontrolled intersections, visibility is provided on the principle that the drivers on either highway are able to sight the intersection in good time and stop their vehicles, if necessary. The sight distance at that intersection should be equal to safe stoppig sigt distance on both the roads. Table 2.7 shows the safe stopping sight distance for different speeds.

Table 2.7

Safe Stopping Sight Distances of Intersections

Speed (kmph)	Safe stopping sight distance (metres)
20	20
25	25
30	30
45	45
50	60
60	80
65	90
80	130
100	180

On priority intersections, the visibility required is such that the driver approaching from minor road should be able to see

the vehicle on major road in adequate time and judge whether the required gap is available in the main road traffic for safe crossing or not. IRC recommends a minimum visibility of 15mt along the minor road. On the major road, sight distance equal to 8seconds travel at design speed is recommended. For obtaining a clear view, the triangular area in the corners of the intersection must be clear of all obstructions to visibility so that both minor and major road traffic remains in full view of each other and mistakes in judgement are avoided.

2.4.8 Channelizing Islands

Proper care should be taken in designing channelizing islands. Well designed islands improves both safety and flow of traffic, whereas indiscrete placement of island can lead to more harm than good. For example a traffic island with high kerbs placed at unlighted location or location with poor visibility can be more hazardous to traffic than an intersection without island. Usually three types of islands will be provided. They are

a. corner islands
b. centre islands
c. pedestrian refuge islands

Corner islands (normally triangular) should meet the following requirements.

a. It should be of sufficient size to be readily identified and visible. It must have an area of atleast 4.5 metres^2 in urban areas and 7 metres^2 in rural areas and should usually be bordered with painted raised kerbs. They should not be less than 3.5metres and preferably 4.5metres on a side after rounding of curves.

b. It should be offset from normal vehicle path by Ø.3 to Ø.6metres.

c. It should be provided with an illuminated sign. It should be of sufficient size to enable placement of such traffic control devices.

Centre islands should meet the following requirements.

a. It should be preceeded by a clearly marked on constructed nuetral area of not less than 1.5seconds travel time at approach speed.

b. It should be offset by about 1.5metres from edge of main carriageway.

c. It should present a smooth, free flowing alignment into and out of the divided road.

d. It should be less than 1.2metres wide and 6metres length.

e. It should permit placement of traffic control devices.

Central refuges are to be considered when the carriageway exceeds 4-lanes. The width of central refuge shall be 1.5metres and above depending on the crossing pedestrian volume and space available. The refuge island should be provided with vertical kerb which should be suitably reflectorised and illuminated.

2.5 Typical Intersection Design

In this section the general method of designing a typical intersection is outlined. The choice of various intersections depends on traffic volume, composition of traffic, design speed, amount of access control and highway type. Various types of intersections that are usually adopted are shown in Fig. 2.2. They are three legged intersection, four legged intersection,

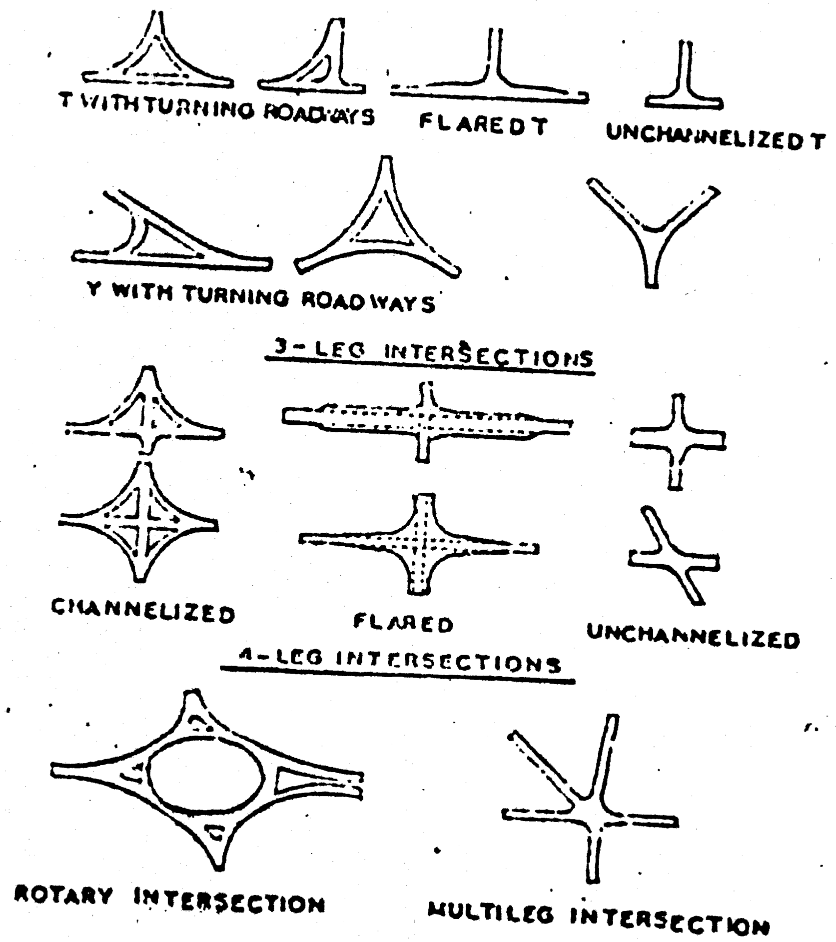

Fig 2.2 General Types of At-Grade Intersections

multilegged intersection and rotary type intersection either with or without signallization.

2.5.1 Selection of Intersection Type

Another factor which improves the safety of an intersection is the proper choice of intersection type. 3-way intersections have fewer accidents in lower speed ranges and more in the higher speed ranges. Accident rates at 3-way intersection have been found to be considerably lower than those on 4-way intersections. For all volume ranges, 4-way intersections are found to have about twice as many accidents as 3-way intersections. Hence it is better to use 3-way intersections in preferrence to 4-way intersections, wherever possible.

The choice of intersection type also depends on the volume of traffic on the major road and the proportion it holds to the traffic on minor road. As traffic increases on the major roads, vehicles on minor road find it more and more difficult to get an acceptable gap in the main traffic stream. The decrease in crossing opportunities causes delays to minor road and tendency is to take risk with smaller gaps than usual. Risks increases accident potential at intersection. In general, as flows on intersecting arms rise so does the requirement for a more sophesticated treatment. Generally the strategy of intersection design should be to gradually introduce special features like channelization, speed change lanes etc., as the traffic increases. This progressive layout is shown in Fig. 2.3.

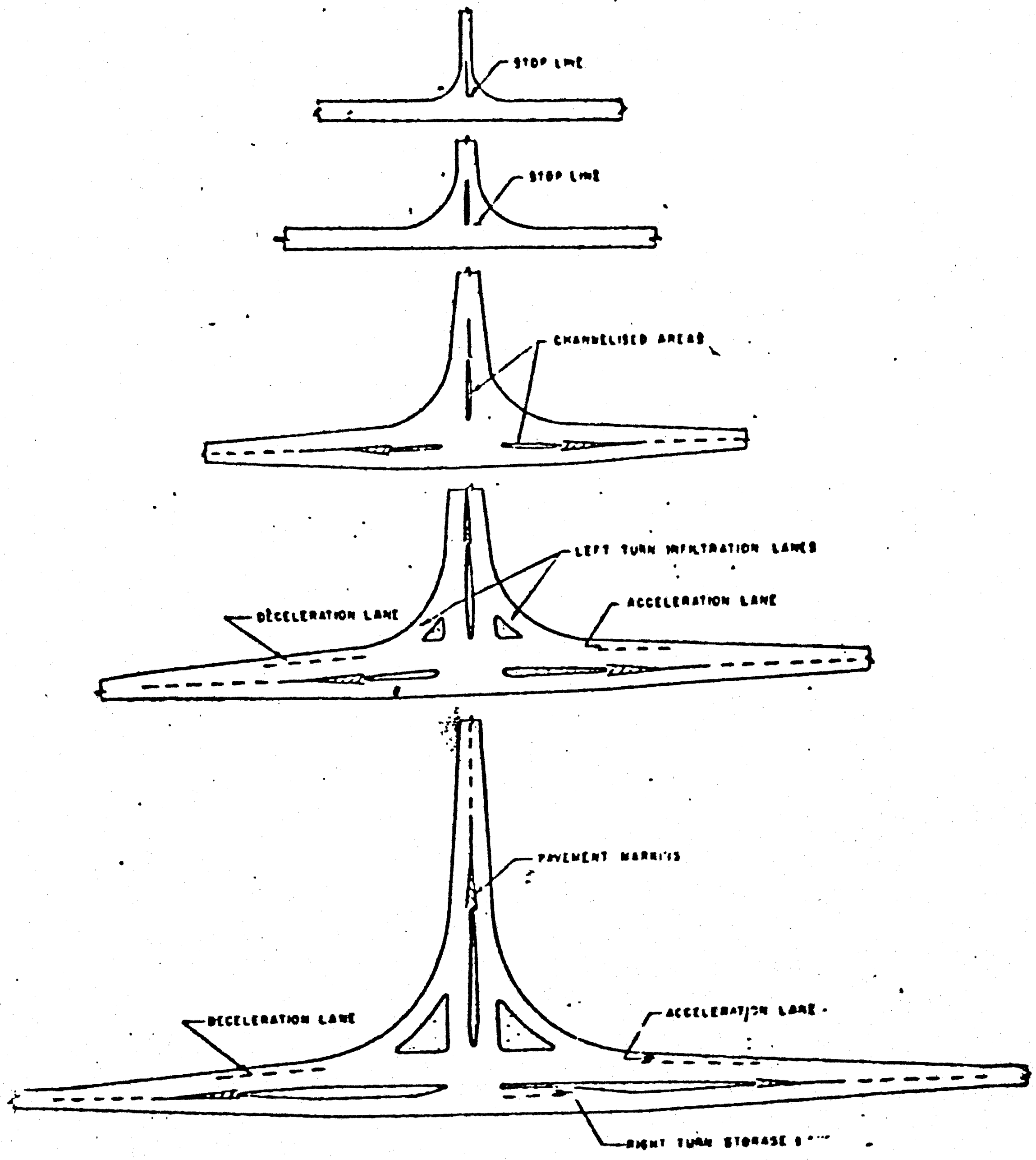

Fig 2.3 Progressive Layouts of T-Junctions f6r Use on Main Highways

2.5.1.1 3-legged Junctions

In case of 3-legged intersection, the layouts which enable right turn from the major roads to be made obliquely are considerably superior because of their low accident rate. The optimum safe angle for such crossings is about 65°. Another principle for 3-legged intersection is that to provide a clear view for driver approaching from minor road. The layout should be such that the right turning manoeuvre from the minor road is not made at too oblique angle. This principle conflicts to some extent with the requirement of easy right turn exist from the major road which requires an oblique angle. To resolve the two opposing requirements, the designer must bring to bear his best skill in the design of central channelizing island on the minor road. Fig 2.4 shows an attempt in this direction.

2.5.1.2 4-way Junctions

Treatment of 4-way junctions is in no way different from 3-arm intersectrions but particular precaution is required to see that angle of crossing is as close to 90° as possible. Skewed crossings increase the area of intersection, thus extending the time of crossing and concomitantly the risk of traffic hold-ups and accidents. Therefore, good design practice consists in realigning as many skewed junctions to square junctions as practicable.

2.5.1.3 Multi-legged Junctions

The junctions with more than 4 legs are known as multi-legged junctions and are preferred very rarely. As the accident rate

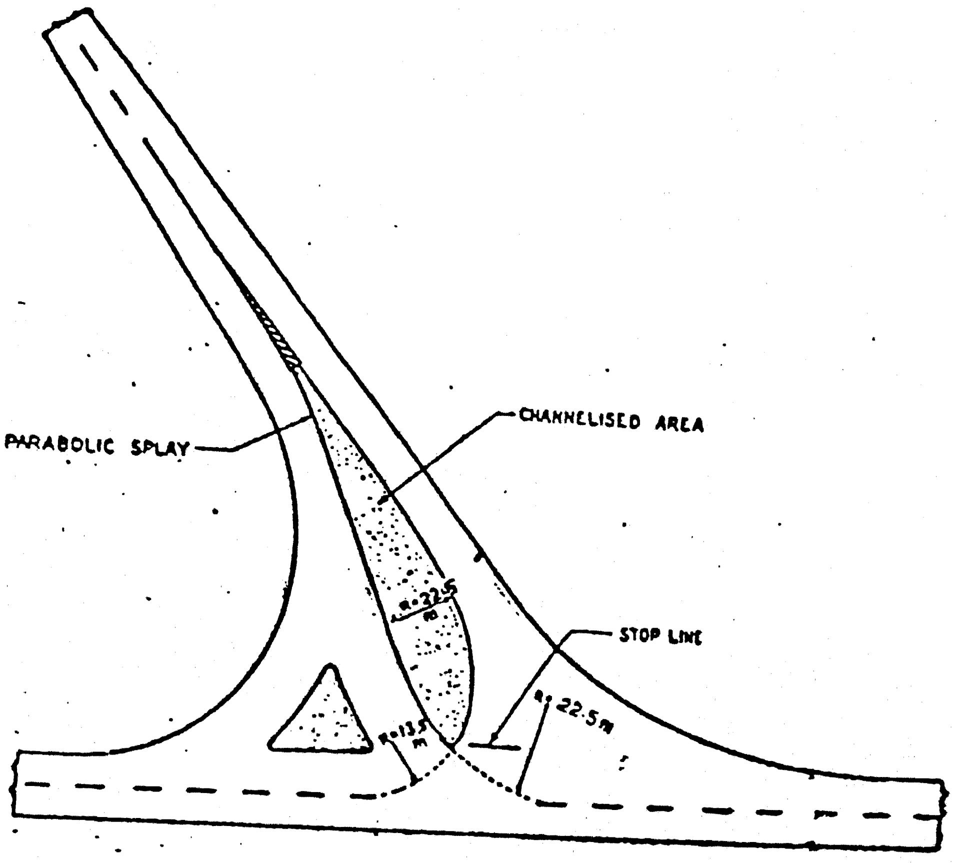

Fig 2.4 Layout of a Splayed Junction

increases with the no. of roads meeting at the intersection, it is not advisable to go for a multi-legged intersections unless otherwise the situation doesn't allow to provide other types of intersections. If possible, the extra legs are to merged into other legs ahead of intersection and taken out after intersection. That is not possible when all the roads are of equal importance and carry heavy traffic. In such a case multi-legged intersections are preferred. When a multi-legged intersection is provided, it is advisable to provide a rotary. In multi-legged intersections, the warrants for rotary will met easily.

2.5.1.4 Rotary Type Intersection

A traffic rotary is a specialised form of at-grade intersection where vehicles from the converging arms are forced to move round an island in one direction in an orderly and regimented manner and weave out of the rotary movement into their desired directions. Rotaries have a number of advantages and disadvantages. Hence care has to be taken in checking the feasibility of the same.

The advantages of traffic rotaries are as follows

a. An orderly and regimented traffic flow is provided. Individual traffic movements are subordinated in favour of traffic as a whole.

b. All traffic proceeds at a fairly uniform speed. Frequent stopiing and starting are avoided.

c. Weaving replaces the usual crossing movements. Direct conflict is eliminated, all traffic streams merging or diverging at small angles. Accidents occuring from such movements are usually of a minor nature.

d. For moderate traffic, rotaries are self governing and need no control by police or traffic signals.

The disadvantages of traffic rotaries are as follows.

a. As the flow increases and reaches the capacity, weaving generally gives way to a stop and go motion as vehicles force their way into the rotary, being followed by vehicle waiting in the queue behind them. Under such conditions, vehicles, once having got into the rotary, may not be able to get out of it, because of vehicles across their path and the rotary may lock-up. Once the rotary has locked-up, the movement of vehicles completely stops and the traffic will have to be ultimately sorted out by the police.

b. A rotary requires a comparatively larger area and may not be feasible in many built-up locations.

c. Where the angle of intersection is too accute, it becomes difficult to provide adequate weaving length.

d. Traffic turning right has to travel a little extra distance.

Considering the above advantages and disadvantages of traffic rotaries, the following general guidelines may be kept in view when adopting a rotary design at an intersection.

a. Rotaries are not generally warranted for intersections carrying very light traffic. Normally the lowest traffic volume for which rotary treatment should be considered is about 500 vehicles/hour.

b. Rotaries are most adaptable where the volumes entering the different intersection legs are approximately equal.

c. The maximum volume that a traffic rotary can handle

efficiently can be taken as about 3000 vehicles/hour entering from all intersecting legs.

d. Rotaries are advantageous in locations where the proportion of right turning traffic at a junction is high. As a rough guide, it may be assumed that at a four-legged junction, a rotary is more justified than traffic signal if the right-turning traffic exceeds about 30% of all approaching traffic.

e. A rotary is preferable if there are other junctions so near that there would be insuficient space for the formation of queues.

2.5.2 Design Details for a Rotary (Ref. 18)

Various design details for a rotary type intersection are outlined in the following few articles.

2.5.2.1 Shape of Rotary Island

The shape and disposition of rotary island depends upon various factors such as the number and disposition of the intersecting roads and traffic flow pattern. The design of the rotary is developed by connecting the one-way entrance and exit roads to form a closed fugure with atleast the minimum weaving lengths interposed between two intersecting legs and then adjusting for the minimum radius of the rotary corresponding to the design speed. Some of the more common shapes are circular, squarish with rounded edges, elliptical, oval etc. Among them circular shaped rotary is preferred for most of the cases.

2.5.2.2 Radii of Curves at Entry and Exit

Radius of curve at the entry is related basically to the design speed, amount of superelevation and coefficient of friction. Since major intersections like rotaries are provided with advance information signs and drivers travel through them with anticipation of more critical conditions than on open highways, the values of coefficient of friction for purposes of design are regarded as higher than for other locations. Based on overall considerations, Table 2.8 gives guidance for the selection of radii of curves at entry.

The radii of the curves at exit should be larger than that of the central island and at entry so as to encourage the drivers to pick up speed and clear away from the rotary expeditiously. For this reason, the radius of the exit curves may be kept about 1 1/2 to 2 times the radius of the entry curves.

Table 2.8

Radii of Curves at Entry of a Rotary

Rotary design speed (kmph)	Radius at entry (metres)
40*	20 - 35
30**	15 - 25

* speed suitable for rotaries in rural areas

** speed suitable for rotaries in urban areas

2.5.2.3 Radius of Central Island

Theoretically, the radius of the central island should be equal to the radius at entry. In practice however, the radius of the central island is kept slightly larger than that of the curve

at entry. This being an attempt to give a slight preference to the traffic already on the rotary and to slow down the approaching traffic. A value of 1.33 times the radius of entry curve is suggested as a general guidenline for adoption.

2.5.2.4 Width of Carriageway at Entry and Exit

The carriageway width at entrance and exit of a rotary is governed by the amount of traffic entering and leaving the rotary. It is recommended that the minimum width of carriageway be atleast 5metres with necessary widening to account for the curvature of the road. Table 2.9 gives the value of the width of carriage way at entry and exit inclusive of widening needed on account of curvature.

Table 2.9

Carriageway Widths for Different Widths of Approach Road and Different Radii at Entry

Carriageway width of the approach road	Radius at entry (metres)	Width of carriage way at entry and exit (metres)
7.Ømetres (2 lanes)	25 - 35	6.5
1Ø.5metres (3 lanes)		7.Ø
14.Ømetres (4 lanes)		8.Ø
21.Ømetres (6 lanes)		13.Ø
7.Ømetres (2 lanes)	15 - 25	7.Ø
1Ø.5metres (3 lanes)		7.5
14.Ømetres (4 lanes)		1Ø.Ø
21.Ømetres (6 lanes)		15.Ø

2.5.2.5 Width of Rotary Carriageway

Fig 2.5 shows weaving section and non-weaving section in rotary. The width of non-weaving section of the rotary should be equal to the widest single entry into the rotary, and should

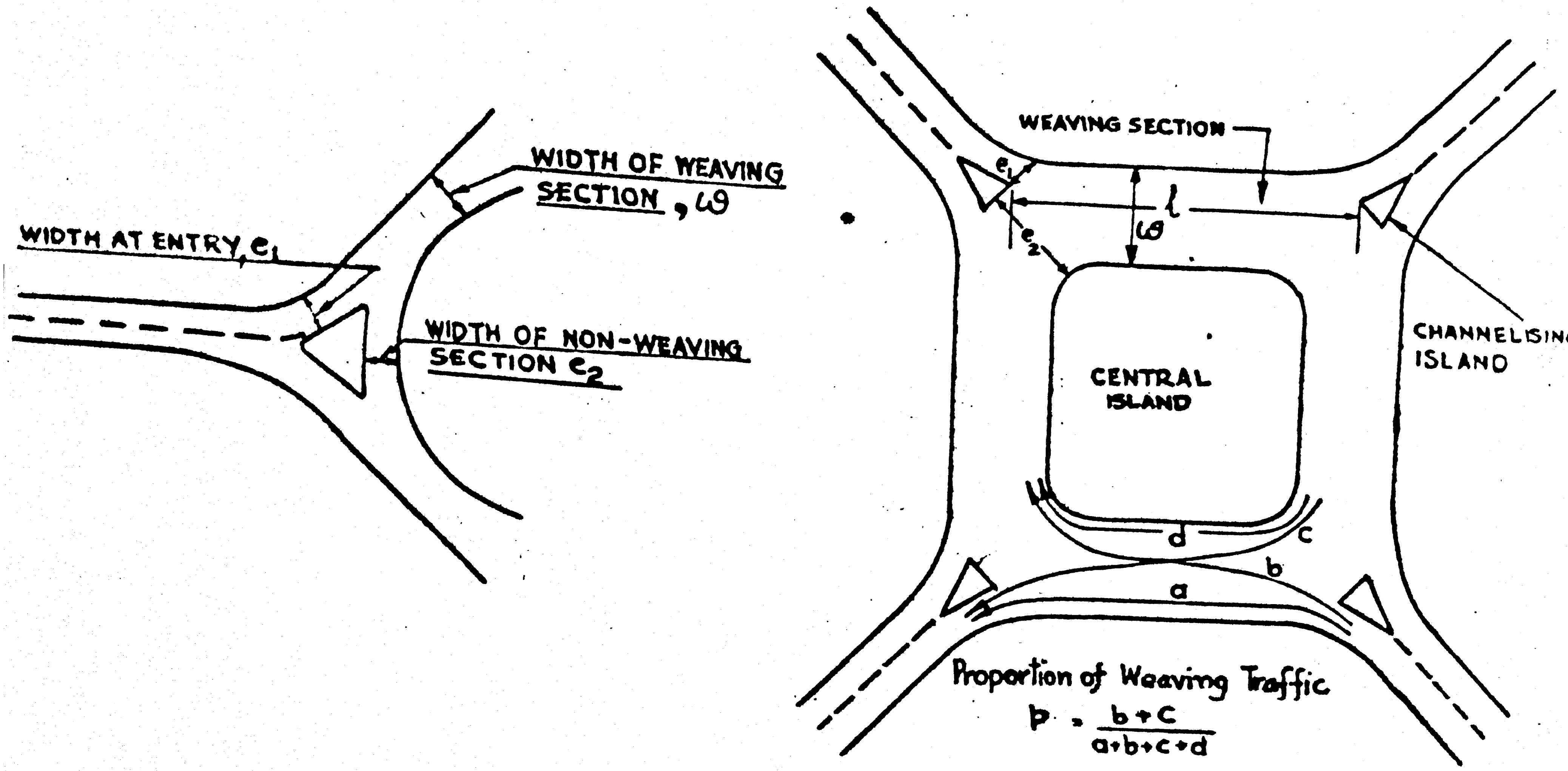

Fig 2.5 Details of Rotary Carriageway

generally be less than the width of the weaving section.

Width of the weaving section of the rotary should be one traffic lane(3.5mt) wider than the mean entry width thereto.

2.5.2.6 Weaving Length

The weaving length determines the ease with which the vehicles can manoeuvre through the weaving section and thus determines the capacity of the rotary. The weaving lengtrh is decided on the basis of factors such as the width of the weaving section, the average width of entry, total traffic and the proportion of weaving traffic in it. As a general rule, effort should be made to keep the weaving length at least 4 times the width of the weaving section. Table 2.10 shows the minimum values of weaving lengths for different design speeds.

Table 2.10

Minimum Weaving Lengths for Design Speeds

Design speed (kmph)	Minimum weaving length (metres)
40	45
30	30

2.5.2.7 Channelizing Islands

Channelizing islands should be provided, wherever necessary the shape of the channelizing island depends on actual conditions obtaining at each site. A few typical designs are illustrated in Fig. 2.6.

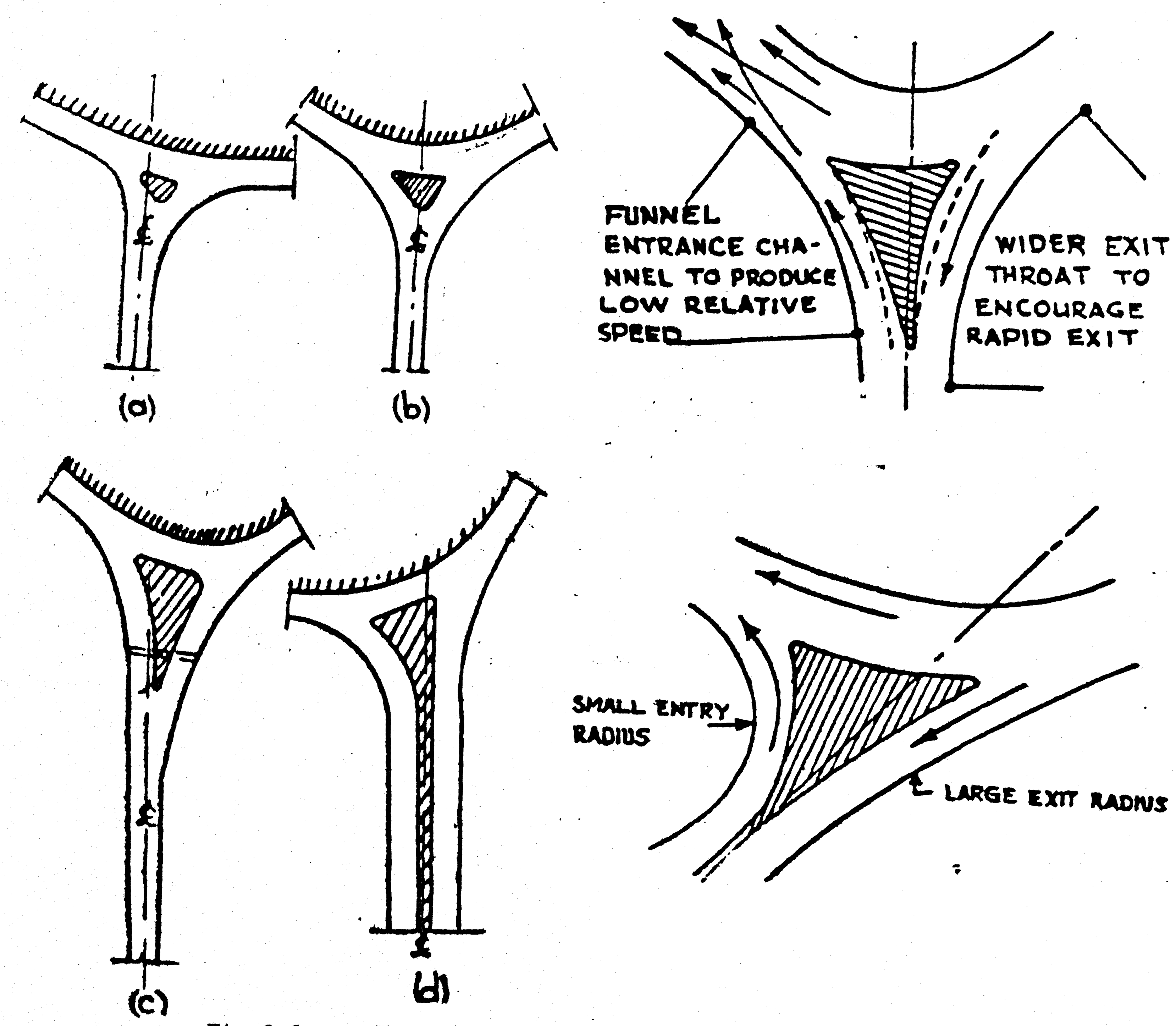

Fig 2.6 Channelizing Island for Rotary Under Different Conditions

2.5.2.8 Camber and Superelevation

Since the rotary curvature is opposite to that of entry and exit, vehicles, especially top-heavy buses and trucks, experience difficulty in changing over from one cross-slope to anothr in the opposite direction. It is, therefore, recommended that the algebraic difference in the cross-slopes be limited to about 0.07. A typical disposition of cross-slopes in a rotary is indicated in Fig. 2.7.

2.5.2.9 Sight Distance

On approaches to the rotary, the sight distance available should enable a driver to discern the channelising and rotary islands clearly. A stopping sight distance appropriate to the approach speed should be ensured.

On the rotary itself, the sight distance should be adequate for vehicles first entering a rotary to see vehicles to their right at a safe distance. Similarly, once a vehicle is on a rotary in the middle of a weaving section, it should be possible for it to see another vehicle ahead of it in the next weaving section at a safe distance. In both the above cases, the stopiing sight distance appropriate to the design speed in the rotary could be taken as the minimum to be provided. As a general guideline, the sight distance for the 30-40kmph speed should range between 30 to 45mt.

2.5.2.10 Capacity of the Rotary

It is important that the geometric design evolved for the rotary should be able to deal with the traffic flow at the end of

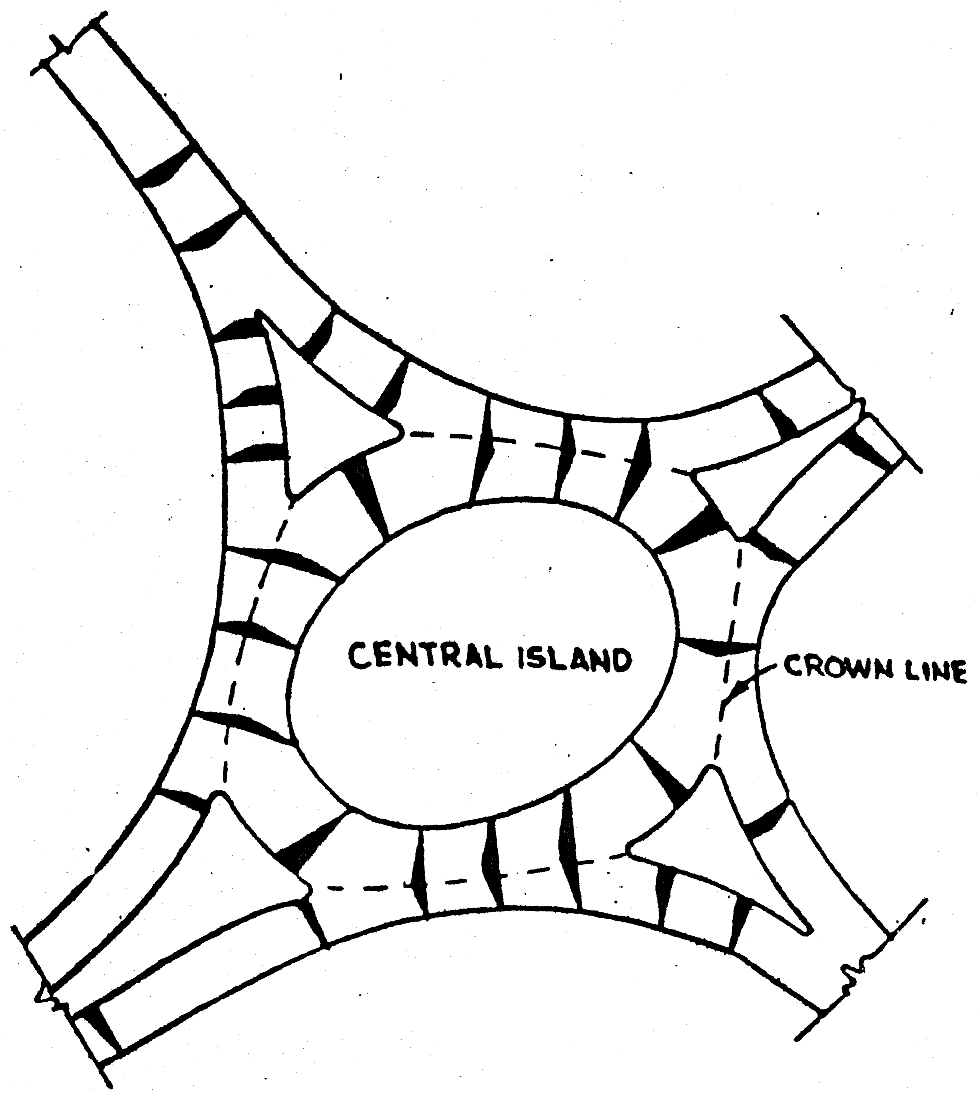

Fig 2.7 Camber and Superelevation at Rotary

the design period on the rotary. The practical capacity of a rotary is really synonymous with the capacity of the weaving section which can accommodate the least traffic. Capacity of the individual weaving sections depends on factors such as

a. width of the weaving section

b. average width of entry into the rotary

c. the weaving length

d. praportion of weaving traffic

It can be calculated from the following formula

$$Q_p = \frac{280 * w * (1 + e/w) * (1 - p/3)}{(1 + w/l)} \qquad \text{-----} \qquad (2.1)$$

where,

Q_p = Practical capacity of the weaving section of the rotary in passenger car units (PCU) per hour,

w = Width of weaving section in metres,

e = average entry width in metres,

l = length in metres of the weaving section between the ends of channelizing islands,

p = Proportion of weaving traffic.

While designing, care shold be exercised that weaving sections are adequate for the required capacity so that merging and diverging manoeuvres take place smoothly. As a major disadvantage with rotaries is the reduction in speed, the weaving sections should preferably kept slightly longer than just necessary for capacity, about 30% more.

2.5.2.11 Other Details for Rotary

A rotary should preferably be located on level ground. It

may be sited to lie on a plane which is inclined to the horizantal at not more than 1 in 50. It is, however, not desirable that a rotary be located in two planes having different inclinations to the horizantal.

The curbs for channelizing and central islands should be either vertical curbs or mountable curbs. In rural sections, it is desirable that the height of the curb of the central island is not more than 225mm and a mountable type is preferable. In urban areas, the curb of the island should not be so high as to obstruct visibility.

Pedestrian crossings and cycle tracks should be suitably provided. It is desirable to seggregate the cyclists by providing seperate cycle tracks.

Rotaries require to be adequately designed for both day and night travel. Red reflectors should be fixed at the nose of each directional island, and on the curb of the central island facing the approach roads. All curves should be painted with black and white stripes. All pedestrian and cyclist crossings should be provided with suitable pavement markings. The standard warning sign indicating the presence of a rotary should be put up in advance on all the approaching roads.

Illumination of the rotary junction at night is very desirable and suitable care has to be encountered in providing various lanterns annd their positions.

Adequate attention should be paid to drainage with in the

area of the rotary junction. Particularly, the water likely to accumulate at the edges of the rotary island should be drained by means of curb and gutter section having an outlet to underground pipes through appropriately placed gully traps.

2.5.3 Signallization of Intersection (Ref. 9)

All types of intersections, mentioned in 2.5.1 can be signallized, if the warrants (described in the next section) are met. If signallization is praposed, care should be taken regarding all the items of designing and installing them.

2.5.3.1 Warrants for Traffic Signal Installation

Traffic control signals should not be installed, unless one or more of the signal warrants specified herein are met. Information should be obtained from traffic and engineering studies and compared with the requirements set forth in the warrants. If these requirements are not met, a traffic signal should not be put in to operation.

2.5.3.1.1 Warrant 1 - Minimum Vehicular Volume

The minimum vehicular volume warrant is intended for application where the volume of intersecting traffic is the principal reason for consideration of signal installation. The warrant is satisfied when the traffic volume given in Table 2.11 exist on major street and on the higher volume minor street approach to the intersection.

2.5.3.1.2 Warrant 2 - Interruption of Continuous Traffic

The interruption of continuous traffic warrant applied to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or hazard in entering or crossing the major street. The warrant is satisfied when the traffic volume given in Table 2.12 exist on the major street and on the higher volume minor street approaching the intersection. In that case signal installation will not seriously disrupt progressive traffic flow.

Table 2.11

Minimum Vehicular Volume for Warrant - 1

Number of lanes for moving traffic on each approach		Motor vehicles/hr on major street	Motor vehicles/hr on higher volume
Major street	Minor street	(total both app.)	minor street app.
1	1	65Ø	2ØØ
2 or more	1	8ØØ	2ØØ
2 or more	2 or more	8ØØ	25Ø
1	2 or more	65Ø	25Ø

Table 2.12

Minimum Vehicular Volume for Warrant - 2

Number of lanes for moving traffic on each approach		Motor vehicles/hr on major street	Motor vehicles/hr on higher volume
Major street	Minor street	(total both app.)	minor street app.
1	1	1ØØØ	1ØØ
2 or more	1	12ØØ	1ØØ
2 or more	2 or more	12ØØ	15Ø
1	2 or more	1ØØØ	15Ø

2.5.3.1.3 Warrant 3 - Minimum Pedestrian Volume

The minimum pedestrian volume warrrant is satisfied when the following traffic volumes exist.

a. On the major street, 600 or more vehicles per hour enter the intersection from both approaches.

b. There are 150 or more pedestrians per hour on the highest volume cross-walk crossing the major street.

2.5.3.1.4 Warrant 4 - Accident Experience

The accident experience warrant is satisfied when

a. Adequate trial of less restrictive remedies with satisfactory observance and enforcement have failed to reduce the accident frequency.

b. Five or more reported accidents, of types susceptible of correction by traffic signal control have occurred within a period of 12 months, each accident involving personal injury or property damage to an apparent extent of Rs.2000 or more.

c. The signal installation will not seriously disrupt traffic flow.

2.5.3.1.5 Warrant 5 - Combination of Warrants

In exceptional cases, signals may be justified occasionally where no signal warrant is satisfied but where two or more of above warrants satisfied to the extent of 80% or more of the stated volume. Adequate trial of other remedial measures which causes less delay and inconvenience to traffic should precede installation of signals under this warrant.

2.5.3.2 Design of Signal Timings

To do design of signal timings, the information that is ded is the widths of all the roads, number of vehicles entering

the junction from all the directions. Then a decision has to be made regarding the number of phases. Minimum green times for all the phases are to be calculated based on pedestrians reaction time and adjusted according to traffic volumes. Amber timings can be fixed up with reference to traffic volumes. Being aware of green and amber timings for all the phases, we can calculate total cycle length and red timings. In that way one can fix up signal timings.

Then check for design of signal cycle timings on the basis of vehicular volume has to be done i.e., whether the green times provided will be sufficient or not to clear off all the vehicles that will be accumulated per cycle length on average. If not, proper modifications are to be done. Then optimisation of signal timings can be done and check the safety of above calculated timings using the Webster's formula

$$C_o = \frac{1.5 * L + 5}{1-Y_1-Y_2..Y_n} \qquad \text{-------} \qquad (2.2)$$

Where,

C_o = Optimum cycle length in seconds,

L = Total lost time per cycle,

Y = Ratio of volume to saturation flow for critical approach in each phase.

2.5.4 Performance Study of Intersections

In this section, it is discussed that how different sorts of designs and types of control devices affect intersection performance. Three types of intersections, namely simple intersections, space-sharing intersections and time-sharing intersections are analysed.

2.5.4.1 Simple Intersections

In this type of intersections it is generally assumed that virtually no delay occurs to the major flow or main highway traffic; thus the most significant aspect of its performance is the effect on the minor flow or side street traffic. Side street vehicles normally are required to come to a full stop before entering the intersection, and then must wait for an acceptable gap in the major flow to pass through the intersection. The delay to side street vehicles is directly related to the size of the time gap a driver thinks he needs to pass through the main stream and to the number of gaps equal to or larger than this required or acceptible gap. The number of gaps of this size is related to the main highway volume. Further the minimum acceptable changes as the side street volume increases and as the main highway volume increases. From simple statistics, it can be easily derived that the probability of being delayed at least one interval is equal to

$$\frac{1}{\lambda e^{-\lambda t}} - \frac{t}{1-e^{-\lambda t}} \qquad \text{-------} \quad (2.3)$$

Where,

λ = mean arrival rate,

t = time gap required for a side street vehicle to clear off the junction.

The probabilities associated with side street vehicles having to wait certain lengths of time for various acceptible gaps and for various major-flow volume levels are shown in Fig. 2.8 (Ref. 16).

2.5.4.2 Space-sharing Intersections (Rotaries)

The delay to vehicles travelling through rotaries consists two parts (Ref. 26).

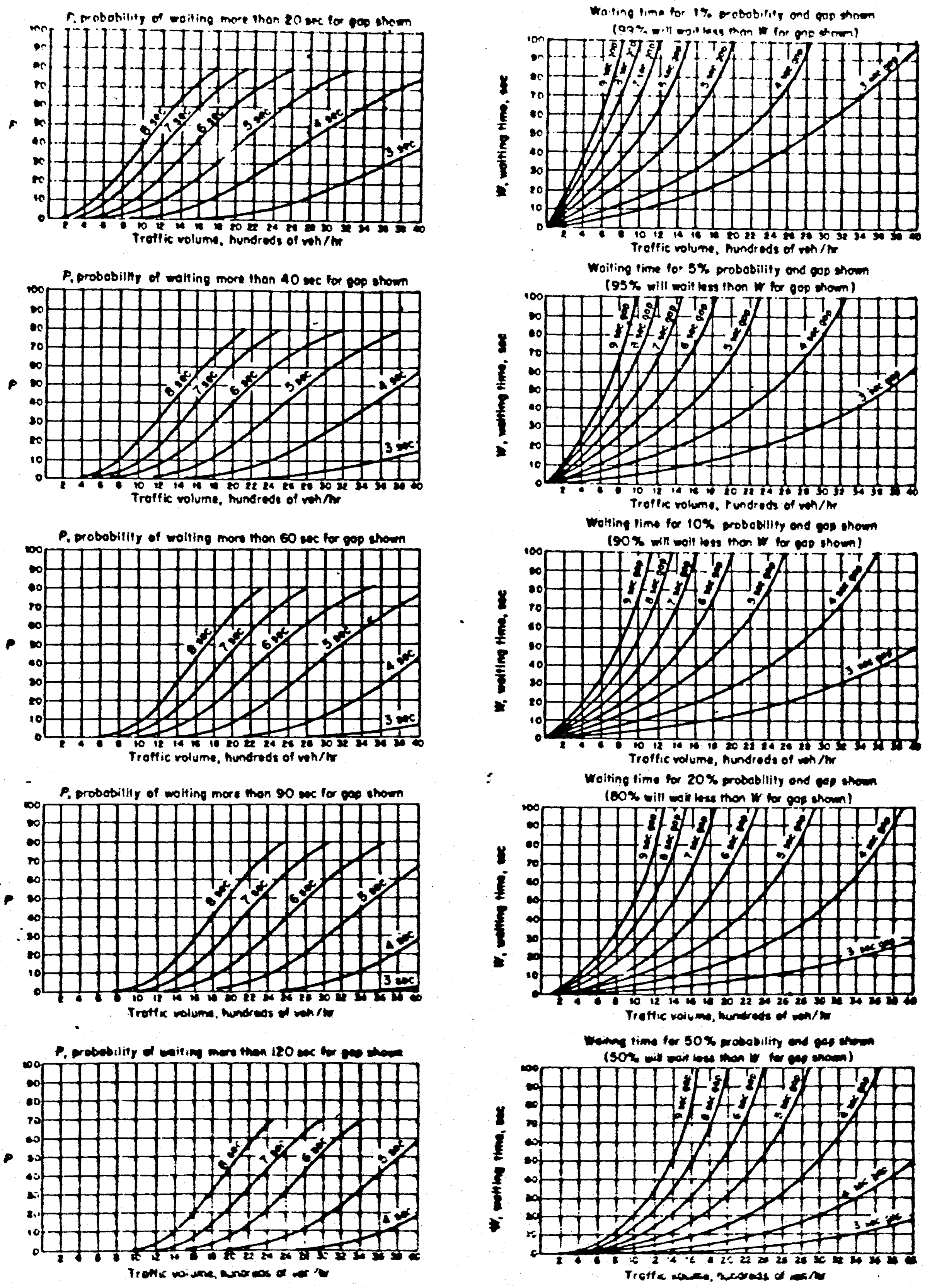

Fig 2.8 Probability of Waiting Specified Lengths of Time for Several Gaps (and Viceversa) at various traffic volume rates for a Simple Intersection

a. Delay caused by slowing down to negotiate the rotary, by travelling extra distance, and by accelerating to normal speed.

b. Delay caused by interaction with other vehicles using the rotary.

The delay due to first component is about 9.0 seconds for a speed of about 50kmph, 12.5seconds for 70kmph, 17.0 seconds for still higher speeds. The delay due to second component is shown in Fig. 2.9 (Ref. 26).

For a signallized rotary delay vs volume curve is shown in Fig. 2.10.

2.5.4.3 Time - sharing Intersections (Signallized Intersections)

The average delay experience per vehicle by the flow on the j^{th} particular approach during the i^{th} phase can be determined from the following equation (Ref. 28).

$$d_j = \frac{C(1-\lambda_i)^2}{2(1-\lambda_i x_j)} + \frac{x_j^2}{2V_j(1-x_j)} - 0.65\ \{C/V_j^2\}^{1/3}\ x_j^{2+5\lambda_i} \quad ---(2.4)$$

where,

d_j = average delay per vehicle for flow on j^{th} approach during the i^{th} phase (sec),

C = cycle length (sec),

λ_i = proportion of cycle length effectively green during i^{th} phase [= $(G_i - K_i)/C$],

V_j = actual volume on j^{th} approach during i^{th} phase, in vehicles/lane/sec,

x_j = degree of saturation for j^{th} approach, (ratio of actual flow to maximum flow) [= $V_j/\lambda_i S$]

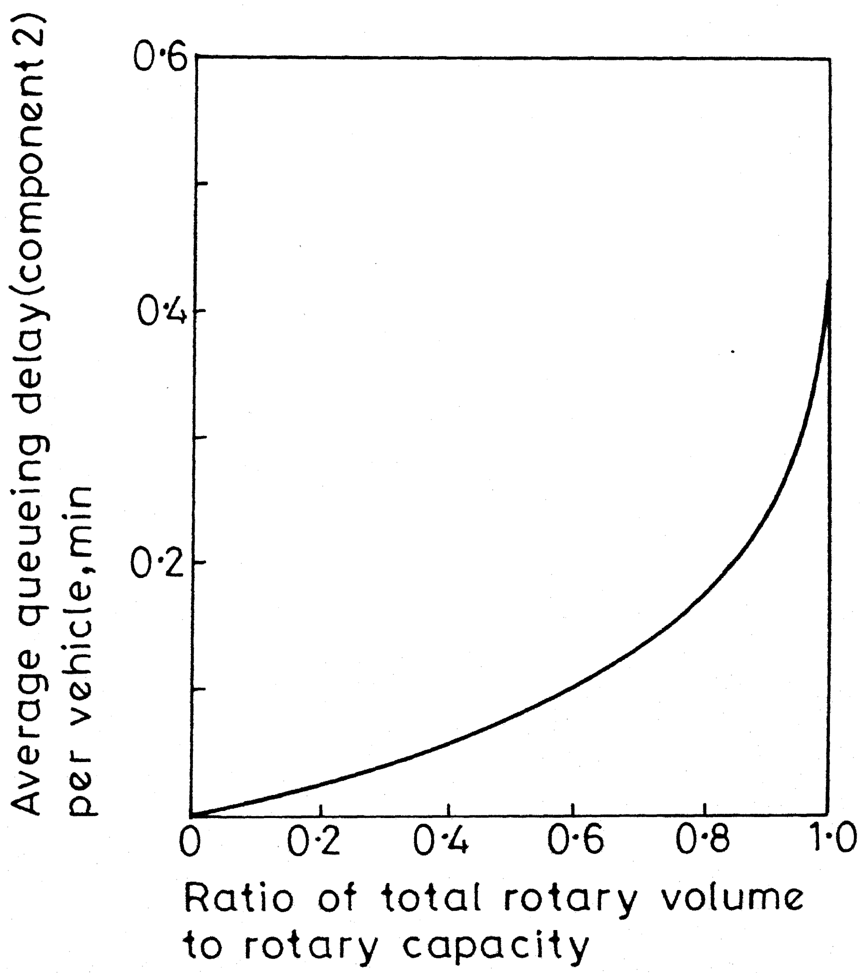

Fig. 2·9 Queuing delay curve for rotary

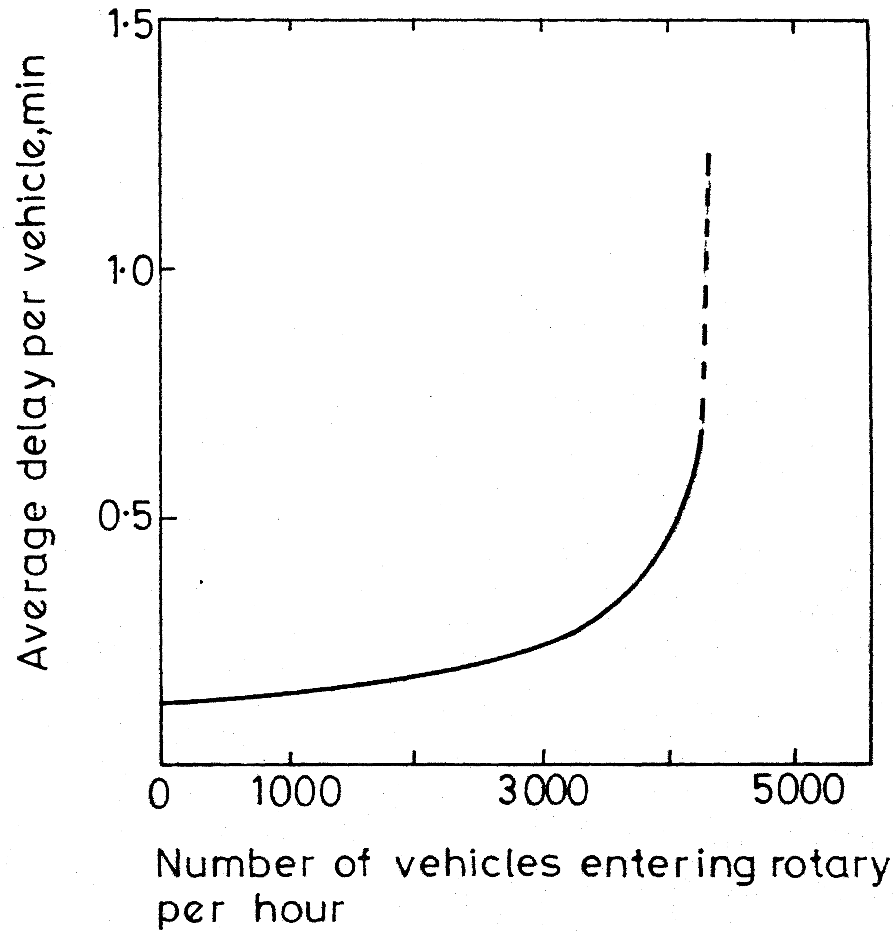

Fig. 2·10 Delay vs. volume curve for Signallized Rotary

S = saturation flow, vehicles/lane/sec (=1/h),

h = minimum vehicle headway at maximum flow.

Once d_j has been calculated, the total hourly delay per lane for the j^{th} approach can be determined simply by multiplying d_j by the hourly lane volume. Finally, the total intersection delay can be computed by summing the delays for all lanes of all approaches at the intersection.

The length of the waiting line, or the queue of vehicles waiting at a signallized intersection, is of particular concern in urban areas where intersections are close together. Long queues of vehicles may block cross traffic at adjacent intersections or may interfere with other important acitivities. Also, excessive queues may interfere with the proper alignment of vehicles making left or right turns. An approximate formula for determing the average queue length at the beginning of the green period for the j^{th} lane is as follows (Ref. 28).

$$n_j = V_j R_i /2 + V_j d_j \quad \text{or} \quad n_j = V_j R_i \quad \text{------} \quad (2.5)$$

whichever is larger.

Where

n_j = average number of vehicles waiting in queue on j^{th} lane at start of green period,

V_j = actual rate of flow for j^{th}lane(vehicles/lane/sec),

R_i = i^{th} red phase (sec),

d_j = average delay per vehicle for j^{th} lane (sec).

CHAPTER III

BUILDING EXPERT SYSTEM

3.1 General

The main items to be performed to build an expert system are explained in this chapter (Ref. 22). Almost all expert systems can be developed in the same way. All the items are explained with reference to our actual problem Intersection Design.

3.2 Defining the Goal and Domain

The first programming task is to objectively define what one is trying to accomplish. The domain should be defined as well as the objects and attributes within this domain. The reasoning process of expert system is search through a problem space. The space represents the domain of knowledge base. On the path to the eventual solutions are sub goals. The basic heuristic is to start with one goal and prove it by proving sub goals. If this proof fails, it goes to next goal and tries to prove it. The basic problem of the knowledge engineer is to define the sub goals. This type of search is known as depth-first search. As heuristic search is being done, it is known as guided-depth-first search.

Let us consider our main problem of designing an intersection. The problem space for that situation can be viewed as shown in Fig 3.1.

In the above mentioned problem space, when we mention our main goal as 'intersection design', expert system tries to prove the first sub goal 'signallized rotary'. In doing so it tries to

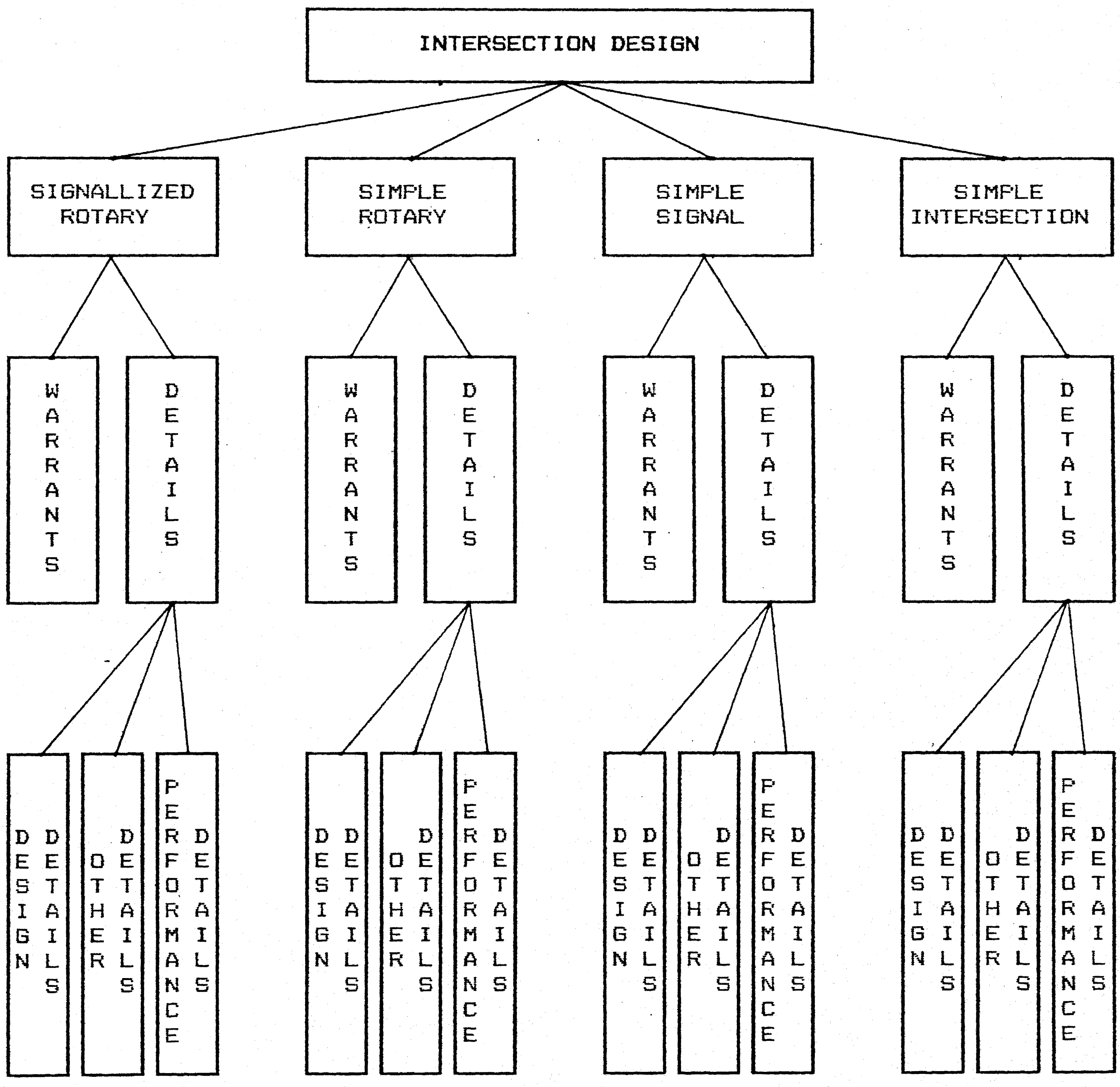

Fig. 3.1 Problem Search Space for Intersection Design

prove its first sub goal 'warrants'. If it succeeds (i.e., actual entered data satisfies the warrants required to provide a signallized rotary), it tries to prove the second sub goal 'details'. To prove 'details', it first proves 'design details' and in doing so it gives all the design details regarding rotary and signal. Then it comes to 'other details' and gives all other minor details such as superelevation, illumination, drainage etc. Then it comes to 'performance details' and gives all the details regarding the performance of the above suggested intersection. When it completes all these cases, our goal 'signallized rotary' succeeds and so our main problem 'intersection design'. If the first sub goal 'warrants' of the goal 'signallized rotary' fails, 'signallized rotary' fails and it backtracks to 'intersection design' but don't execute the second sub goal 'details'. Then it tries to prove another goal 'simple rotary' The execution progresses in this manner during the search procedure. If not even a single goal is successful, then the main goal 'intersection design' is assumed to have failed indicating that none of the four types chosen to analyze the problem are not suitable for that intersection.

3.3 Getting facts

Once the object of the systm is defined, the next task is to list the facts necessary to reach each possible conclusion. There must be enough facts to positively identify each conclusion. For example, for the 'warrants clause of 'rotary type intersection', the facts that are needed are as follows.

Number of legs of intersection should be greater than or equal to four,

Total number of vehicles entering the intersection from all the legs should be greater than 2000 and less than or equal to 3500,

Total right turns at the intersection should be greater than or equal to 30% of total volume.

As another example, to provide a simple signallized intersection at least one of the following conditions should be satisfied.

a. When number of lanes on major street are equal to one and number of lanes on minor street are equal to one, then number of vehicles per hour on major street (from both approaches) should be greater than or equal to 650 and on minor street (from higher volume approach) should be greater than or equal to 200.

When number of lanes on major street are equal to two or more and number of lanes on minor street are equal to one, then number of vehicles per hour on major street (from both approaches) should be greater than or equal to 800 and on minor street (from higher volume approach) should be greater than or equal to 200.

When number of lanes on both the streets are two or more, then the number of vehicles per hour on major street (from both approaches) should be greater than or equal to 800 and on minor street (from higher volume approach) should be greater than or equal to 250.

When number of lanes on major street are equal to one and number of lanes on minor street are equal to or more than

two, then number of vehicles per hour on major street (from both approaches) should be greater than or equal to 650 and on minor street (from higher volume approach) should be greater than or equal to 250.

b. When number of lanes on major street are equal to one and number of lanes on minor street are equal to one, then number of vehicles per hour on major street (from both approaches) should be greater than or equal to 1000 and on minor street (from higher volume approach) should be greater than or equal to 100.

When number of lanes on major street are equal to two or more and number of lanes on minor street are equal to one, then number of vehicles per hour on major street (from both approaches) should be greater than or equal to 1200 and on minor street (from higher volume approach) should be greater than or equal to 100.

When number of lanes on both the streets are two or more, then the number of vehicles per hour on major street (from both approaches) should be greater than or equal to 1200 and on minor street (from higher volume approach) should be greater than or equal to 150.

When number of lanes on major street are equal to one and number of lanes on minor street are equal to or more than two, then number of vehicles per hour on major street (from both approaches) should be greater than or equal to 1000 and on minor street (from higher volume approach) should be greater than or equal to 150.

c. Volume on major street should be greater than or equal to 600 vehicles per hour when total number of pedestrians crossing the intersection are more than or equal to 150 per hour.

Like this facts are to be established for all the rules.

3.4 Structuring the Program

Once the above two are completed, one can begin writing the program. As already explained, in expert systems writing the program means writing the rules and calling them in the required order.

In 'Prolog' the facts mentioned in article 3.2 can be expressed as rules in the following fashion.

```
rotary_warrants (Nlegs,Total_volume,Right_turns) :-

        Nlegs >= 4,
        Total_volume <= 3500,
        Total_volume >  2000,
        Right_turns  >  0.3*Total_volume.
```

The above mentioned one is the warrants rule for rotary. Before asking Prolog to prove 'rotary_warrants', all the variables Nlegs, Total_volume, Right_turns should be bound. When it is called to prove, the Prolog tries to prove Nlegs >= 4 first. If it succeeds, it proves the second clause Total_volume <= 3500. If this one also succeeds, it goes to third one. The execution progresses in this manner. If at any stage, any one of the four clauses fails, the rule rotary_warrants fails and Prolog backtracks to that location from where it has come. The rule for the second fact signal_warrants can be written as follows.

```
signal_warrants(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU,_) :-

     warrant_one(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU).

signal_warrants(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU,_) :-

     warrant_two(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU).

signal_warrants(_,_,Major_PCU,_,Pedestrians) :-

     warrant_three(Major_PCU,Pedestrians).

warrant_one(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes = 1,
     Minor_lanes = 1,
     Major_PCU >= 650,
     Minor_PCU >= 200.

warrant_one(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes>= 2,
     Minor_lanes = 1,
     Major_PCU >= 800,
     Minor_PCU >= 200.

warrant_one(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes>= 2,
     Minor_lanes>= 2,
     Major_PCU >= 800,
     Minor_PCU >= 250.

warrant_one(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes = 1,
     Minor_lanes>= 2,
     Major_PCU >= 650,
     Minor_PCU >= 250.

warrant_two(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes = 1,
     Minor_lanes = 1,
     Major_PCU >= 1000,
     Minor_PCU >= 100.

warrant_two(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes>= 2,
     Minor_lanes = 1,
     Major_PCU >= 1200,
     Minor_PCU >= 100.
```

```
warrant_two(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes>= 2,
     Minor_lanes>= 2,
     Major_PCU >= 1200,
     Minor_PCU >= 150.

warrant_two(Major_lanes,Minor_lanes,Major_PCU,Minor_PCU) :-

     Major_lanes = 1,
     Minor_lanes>= 2,
     Major_PCU >= 1000,
     Minor_PCU >= 150.


warrant_three(Major_PCU,Pedestrians) :-

     Major_PCU >= 600,
     Pedestrians >= 150.
```

Before asking Prolog to check whether the rule 'signal_warrants' succeeds or not, all the variables, namely, Major_lanes, Minor_lanes, Major_PCU, Minor_PCU, Pedestrians should be bound. The execution proceeds in the following manner. To prove 'signal_warrants', Prolog tries to prove 'warrant_one' first as it is the first mentioned one. In doing so, it tries to prove first rule of 'warrant_one'. If all the four conditions i.e., Major_lanes=1, Minor_lanes=1, Major_PCU>=650, Minor_PCU>=200 satisfy, 'warrant_one' is succeeded and hence 'signal_warrants'. If first rule of 'warrant_one' fails it tries to prove second rule. If this one too fails, it tries for third or fourth ones. If none of them succeeds, 'warrant_one' is assumed to have failed. It implies that provision of signal on the basis of first warrant is not feasible. Then Prolog tries for 'warrant_two'. If this one too fails, it tries 'warrant_three'. If Prolog could prove any of the three warrants, it says to provide a signal. If none of them succeeds, it says provision of signal is not feasible for that intersection.

As mentioned above, rules are to be written for all the facts. Care should be taken in calling them i.e., warrants, design_details, other_details, performance_details. By the time of calling any rule, all the variables that are required to prove that rule should be bound (except those for which values will be assigned in that rule). To prove the same conclusion some variables may be needed in one rule and may not be in other rule (like Pedestrians in this case). At that time one can use an anonymous variable, '_' where it is not needed. The program should be made complete in all respects.

3.5 Testing

Once the program is completed, it should be tested for each hypothesis against the original list of facts. Verification has to be done to see each conclusion is reached properly according to the specifications entered. During this process when logical errors are encountered proper corrections are to be made.

CHAPTER IV

CASE STUDIES, RESULTS AND DISCUSSION

4.1 General

To run the program user needs the following files either in hard disk or floppy disk in a Personal Computer.

PROLOG.EXE

PROLOG.OVL

INTDES.EXE

INTDES.OBJ

INTDES.SYM

To run the program, user has to enter INTDES and press return key. Then Prolog starts execution and then he has to answer the questions it asks. During the execution process, it gives results also. This process is mentioned in articles 4.3 and 4.6. The output of the program is shown in italics, whereas user responses in standard letters. The program has been executed for two actual field problems. The results obtained from the program are drawn as the sketches. The Consultation Paradigms are also outlined.

4.2 Description of Problem - One

Intersection is to be designed for the following data.

Intersection is situated on an arterial street of an urban area.

Width of major road is 14.0 mts.

Turning traffic is available only interms of PCU but not in detail.

4.3 Consultation Paradigm for Problem - One

A>INTDES

Hello

Welcome to INTDES

Expert System for INTersection DESign

Press any key

What is the nature of area? Urban or Rural
Enter 1 for Urban area
Enter 2 for Rural area
1

Enter 1 if it is Arterial street
Enter 2 if it is Sub-arterial street
Enter 3 if it is Collection street
Enter 4 if it is Local street
1

Is it an existing intersection or new one (type old/new)
old -

You give numbers to all the four legs giving 3 and 4 to minor road
3 should be to the left of 1 and right of 2
4 should be to the right of 1 and left of 2
TAKE CARE IN NUMBERING THE LEGS
Now enter the peak hour traffic volume/hour
Can you enter all the turning traffic detailly for all types of vehicles? (y/n)
n

In that case,
Enter total no. of vehicles in PCU going from leg 1 to leg 2
557

Enter total no. of vehicles in PCU going from leg 1 to leg 3
269

Enter total no. of vehicles in PCU going from leg 1 to leg 4
400

Enter total no. of vehicles in PCU going from leg 2 to leg 1
477

Enter total no. of vehicles in PCU going from leg 2 to leg 3
147

Enter total no. of vehicles in PCU going from leg 2 to leg 4
350

Enter total no. of vehicles in PCU going from leg 3 to leg 1
248

Enter total no. of vehicles in PCU going from leg 3 to leg 2
193

Enter total no. of vehicles in PCU going from leg 3 to leg 4
110

Enter total no. of vehicles in PCU going from leg 4 to leg 1
211

Enter total no. of vehicles in PCU going from leg 4 to leg 2
249

Enter total no. of vehicles in PCU going from leg 4 to leg 3
121

Enter the number of Pedestrians who crosses the intersection on all the ways
500

Enter the width of Major road in mts.
14
For the new road the recommendedwidths are as follows
Width of Single lane is 4.50 mts.
Width of Two lane streetis 7.30 mts.
Now enter the width of minor road that you can provide
7

For the present case,
Provide a circulal shaped rotary with the following specifications
[Press any key to continue]

Radius of central island should be about 28mts.
Radius of curve at entry should be about 20mts.
Radius of curve at exit should be about 35mts.
[Press any key to continue]

Width of carriageway at entry and exit should be about10.0mts.

What is the width of widest vehicle you expect into the intersection?
2.8
Width of non weaving section should be about 3.3mts.
Width of weaving section should be about 10.15mts.
Length of weaving portion should be about 41mts.
[Press any key to continue]

Provide four channelizing islands with the following specifications

The radius on the exit side should be as more as possible
The radius on the entry side should be comparatively less
Provide triangular islands at the entrance from minor road
Provide triangular islands with the extended medians on to

```
    the road at the entrance from major road
[Press any key to continue]

Specifications for sight distance :
1. On approaches to the rotary minimum stopping sight distance
   appropriate to the approach speed should be provided
   This value is about 130mts.
2. The stopping sight distance in the rotary should be about 40mts.
[Press any key to continue]

Specifications for external curb line :
The external curb line of weaving sections should not be re-entrant
It should be almost of the same sense as the entry and exit curves

Specifications for Camber and Superelevation :
The crown line should as far as possible be located such that
vehicles cross it while travelling along the common tangent
to the reverse curve
Channelizing islands should be situated on the peak with the
road surfaces sloping away from them to all sides
[Press any key to continue]

General spefications for rotary :
1. It should preferably located on level ground
2. The curbs for channelizing and central islands should either be
   of Vertical of Mountable type
3. Red reflectors should be fixed at the nose of each directional
   island and on the curb of the central island facing the approach
4. Standard warning sign indicating the presence of a rotary
   should be put up in advance on all the approaches
5. Suitable illumination should be provided at the junction
6. Adequate attention should be paid to drainage within
   the area of rotary junction
[Press any key to continue]

Performance characteresticsof the above provided
rotary intersection are as follows

1. Its capacity is 3771 nos. P C U.
2. Average delay per vehicle caused by slowing down
   to negotiate the rotary is about 17 secs.
3. Average delay per vehicle caused due to interactions
   with other vehicles is about 15 secs.

Press the SPACEBAR

A>
```

4.4 Discussion on Results for Problem - One

For the entered data, the program recommended to provide a rotary. The program has given all the details i.e., radius of central island, radii of curves at entry and exit, widths of

weaving and non-weaving sections of rotary and many other minor details such as sight distance, channelizing islands etc. The layout drawn according to the results is shown in Fig. 4.1

Regarding performance characterestics, capacity of the above recommended rotary is 3771 nos. PCU which is about 1.14 times the volume of 3332 nos. PCU. The average delay per vehicle because of slowing down to negotiate the rotary is about 17seconds. and that due to interaction of other vehicles is about 15seconds. These are average values and may be high or low for individual cases. These values are very well within the design limits of 25seconds.

4.5 Description of Problem - Two

Intersection is to be designed for the following data.

- Intersection is situated on a Major District Road in a Plain Terrain of a Rural area.

Width of major road is 12.Ømts.

Turning traffic volumes are available for all the individual types of vehicles.

4.6 Consultation Paradigm for Problem - Two

What is the nature of area? Urban or Rural
Enter 1 for Urban area
Enter 2 for Rural area
1

What is the level of highway?
Enter 1 if it is National or State Highway
Enter 2 if it is Major District Road
Enter 3 if it is Other District Road
Enter 4 if it is Village Road
2

What is the nature of Terrain
Enter 1 if it is Plain Terrain

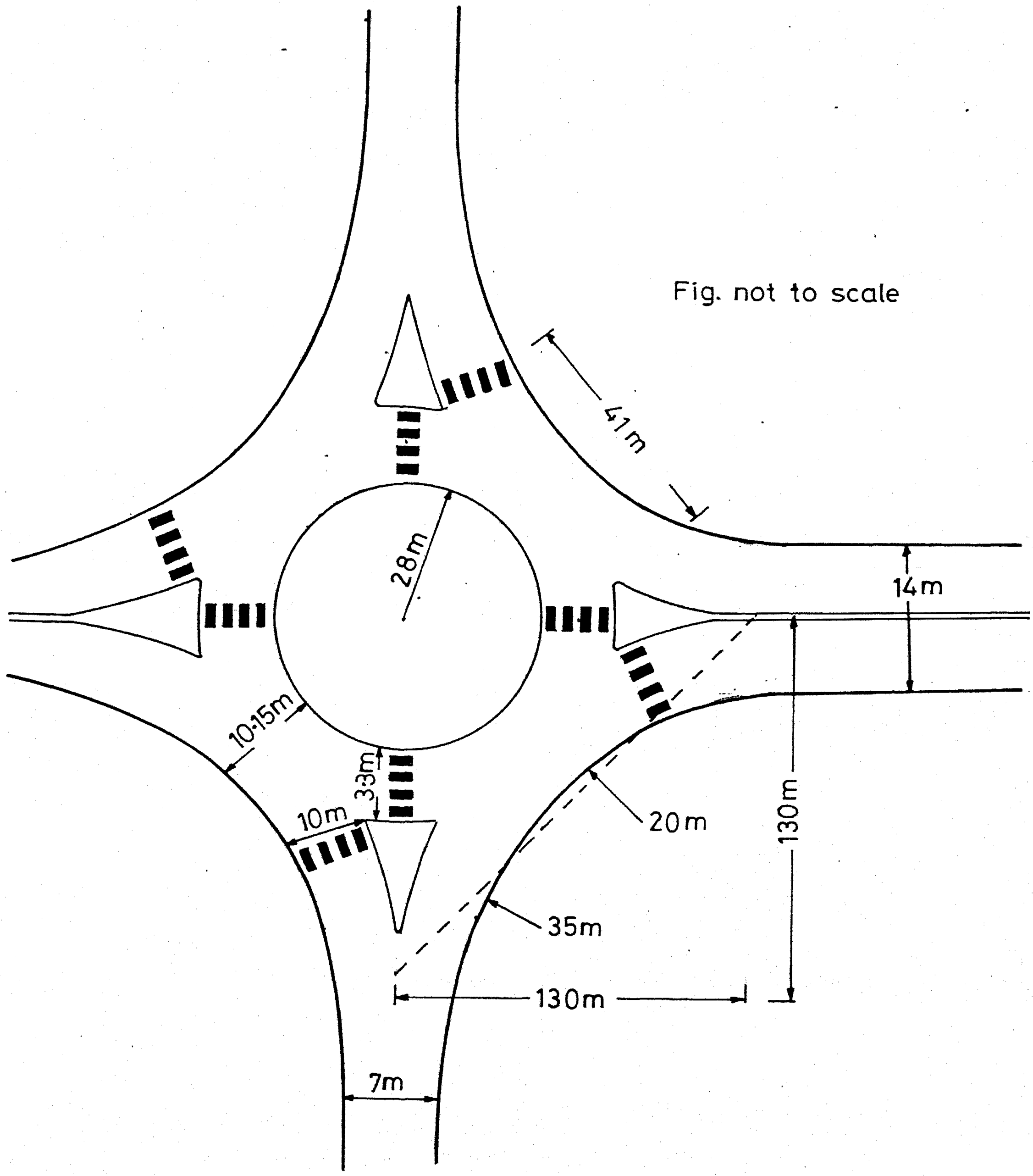

FIG. 4·1 SUGGESTED INTERSECTION LAYOUT FOR PROBLEM ONE

Enter 2 if it is Rolling Terrain
Enter 3 if it is Mountainous Terrain
Enter 4 if it is Steep Terrain
1

Is it an existing intersection or new one (type old/new)
new
For this case provide a four legged intersection.

You give numbers to all the four legs giving 3 and 4 to minor road
3 should be to the left of 1 and right of 2
4 should be to the right of 1 and left of 2
TAKE CARE IN NUMBERING THE LEGS
Now, enter the peak hour traffic volume/hour
Can you enter all the turning traffic detailly for all types of vehicles? (y/n)
y

Then
Enter the no. of Passenger Cars, Tempos etc., going from leg 1 to leg 2
21

Enter the no. of Motor Cycles, Scooters etc., going from leg 1 to leg 2
69

Enter the no. of Trucks Buses etc. going from leg 1 to leg 2
63

Enter the no. of Cycles going from leg 1 to leg 2
11

Enter the no. of Rickshaws going from leg 1 to leg 2
5

Enter the no. of Horse drawn vehicles going from leg 1 to leg 2
Ø

Enter the no. of Bullock carts going from leg 1 to leg 2
Ø

Enter the no. of Passenger Cars, Tempos etc., going from leg 1 to leg 3
7

Enter the no. of Motor Cycles, Scooters etc., going from leg 1 to leg 3
41

Enter the no. of Trucks Buses etc. going from leg 1 to leg 3
18

Enter the no. of Cycles going from leg 1 to leg 3
24

Enter the no. of Rickshaws going from leg 1 to leg 3
11

Enter the no. of Horse drawn vehicles going from leg 1 to leg 3
1

Enter the no. of Bullock carts going from leg 1 to leg 3
3

Enter the no. of Passenger Cars, Tempos etc., going from leg to leg 4
4

Enter the no. of Motor Cycles, Scooters etc., going from leg 1 to leg 4
29

Enter the no. of Trucks Buses etc. going from leg 1 to leg 4
13

Enter the no. of Cycles going from leg 1 to leg 4
19

Enter the no. of Rickshaws going from leg 1 to leg 4
10

Enter the no. of Horse drawn vehicles going from leg 1 to leg 4
2

Enter the no. of Bullock carts going from leg 1 to leg 4
5

Enter the no. of Passenger Cars, Tempos etc., going from leg 2 to leg 1
34

Enter the no. of Motor Cycles, Scooters etc., going from leg 2 to leg 1
86

Enter the no. of Trucks Buses etc. going from leg 2 to leg 1
67

Enter the no. of Cycles going from leg 2 to leg 1
13

Enter the no. of Rickshaws going from leg 2 to leg 1
7

Enter the no. of Horse drawn vehicles going from leg 2 to leg 1
0

Enter the no. of Bullock carts going from leg 2 to leg 1
0

Enter the no. of Passenger Cars, Tempos etc., going from leg 2 to leg 3
11

Enter the no. of Motor Cycles, Scooters etc., going from leg 2 to leg 3
27

Enter the no. of Trucks Buses etc. going from leg 2 to leg 3
24

Enter the no. of Cycles going from leg 2 to leg 3
27

Enter the no. of Rickshaws going from leg 2 to leg 3
12

Enter the no. of Horse drawn vehicles going from leg 2 to leg 3
Ø

Enter the no. of Bullock carts going from leg 2 to leg 3
3

Enter the no. of Passenger Cars, Tempos etc., going from leg 2 to leg 4
9

Enter the no. of Motor Cycles, Scooters etc., going from leg 2 to leg 4
32

Enter the no. of Trucks Buses etc. going from leg 2 to leg 4
1Ø

Enter the no. of Cycles going from leg 2 to leg 4
23

Enter the no. of Rickshaws going from leg 2 to leg 4
14

Enter the no. of Horse drawn vehicles going from leg 2 to leg 4
3

Enter the no. of Bullock carts going from leg 2 to leg 4
4

Enter the no. of Passenger Cars, Tempos etc., going from leg 3 to leg 1
14

Enter the no. of Motor Cycles, Scooters etc., going from leg 3 to leg 1
52

Enter the no. of Trucks Buses etc. going from leg 3 to leg 1
12

Enter the no. of Cycles going from leg 3 to leg 1
34

Enter the no. of Rickshaws going from leg 3 to leg 1
15

Enter the no. of Horse drawn vehicles going from leg 3 to leg 1
2

Enter the no. of Bullock carts going from leg 3 to leg 1
2

Enter the no. of Passenger Cars, Tempos etc., going from leg 3 to leg 2
17

Enter the no. of Motor Cycles, Scooters etc., going from leg 3 to leg 2
31

Enter the no. of Trucks Buses etc. going from leg 3 to leg 2
8

Enter the no. of Cycles going from leg 3 to leg 2
26

Enter the no. of Rickshaws going from leg 3 to leg 2
11

Enter the no. of Horse drawn vehicles going from leg 3 to leg 2
2

Enter the no. of Bullock carts going from leg 3 to leg 2
3

Enter the no. of Passenger Cars, Tempos etc., going from leg 3 to leg 4
6

Enter the no. of Motor Cycles, Scooters etc., going from leg 3 to leg 4
14

Enter the no. of Trucks Buses etc. going from leg 3 to leg 4
5

Enter the no. of Cycles going from leg 3 to leg 4
13

Enter the no. of Rickshaws going from leg 3 to leg 4
20

Enter the no. of Horse drawn vehicles going from leg 3 to leg 4
5

Enter the no. of Bullock carts going from leg 3 to leg 4
11

Enter the no. of Passenger Cars, Tempos etc., going from leg 4 to leg 1
13

Enter the no. of Motor Cycles, Scooters etc., going from leg 4 to leg 1
33

Enter the no. of Trucks Buses etc. going from leg 4 to leg 1
11

Enter the no. of Cycles going from leg 4 to leg 1
31

Enter the no. of Rickshaws going from leg 4 to leg 1
7

Enter the no. of Horse drawn vehicles going from leg 4 to leg 1
1

Enter the no. of Bullock carts going from leg 4 to leg 1
2

Enter the no. of Passenger Cars, Tempos etc., going from leg 4 to leg 2
19

Enter the no. of Motor Cycles, Scooters etc., going from leg 4 to leg 2
31

Enter the no. of Trucks Buses etc. going from leg 4 to leg 2
16

Enter the no. of Cycles going from leg 4 to leg 2
37

Enter the no. of Rickshaws going from leg 4 to leg 2
9

Enter the no. of Horse drawn vehicles going from leg 4 to leg 2
2

Enter the no. of Bullock carts going from leg 4 to leg 2
3

Enter the no. of Passenger Cars, Tempos etc., going from leg 4 to leg 3
6

Enter the no. of Motor Cycles, Scooters etc., going from leg 4 to leg 3
9

Enter the no. of Trucks Buses etc. going from leg 4 to leg 3
5

Enter the no. of Cycles going from leg 4 to leg 3
14

Enter the no. of Rickshaws going from leg 4 to leg 3
17

Enter the no. of Horse drawn vehicles going from leg 4 to leg 3
5

Enter the no. of Bullock carts going from leg 4 to leg 3
1Ø

Enter the no. of Pedestrians who crosses the intersection in all directions
46Ø

Enter the width of major road in mts.
12
For the new road the recommended widths are as follows
Width of single lane is 4.5mts.
Width of two lane street is 7.3mts.
Now enter the width of minor road that you can provide
6

For this case provision of a rotary is not feasible
Hence do not provide the same.

Provide a signallized intersection.
The details are as follows
[Press any key to continue]

THE DETAILS OF TWO PHASE SIGNAL TIMINGS ARE AS FOLLOWS

Signal timing	Initial Amber	Green Time	Clearance Amber	Red Time	Cycle Length
Major	2	24	2	22	50
Minor	2	18	2	28	50

[Press any key to continue]

Various other details are as follows

As it is a right angled Intersection provide a 3-centered symmetrical coumpound curve of radii 36.6-12.2-36.6.

Provide a superelevation of 0.040mts.

In this case sight line is a line joining the points of distance 180mts. on both roads measured from the centre of Intersection. There should not be any obstructions in this triangle.
[Press any key to continue]

Provide four corner islands with the following specifications
a. Size of the triangular island is 3.5mts.
b. The minimum offset from normal vehicle path should be 40cms.

Provide four centre islands with the following specifications
a. Provide a width of 1.0mts.
b. Provide a length of 6.0mts.
c. The minimum offset from normal vehicle path should be 1.50mts.
d. Provide the island such that it gives smooth and free flowing alignment into and out of it.
[Press any key to continue]

Performance characterestics of the above provided intersection are as follows

The average delay per vehicle in seconds, total delay in hours and queue length (average/phase) for each lane are as follows

Lane number	Average delay secs/veh	Total delay hours	Queue length nos/phase
1	13.05	1.93	2
2	13.45	2.18	2
3	17.20	2.14	4
4	16.50	1.97	4

4.7 Discussion on results for Problem - Two

For the entered data, the program recommended to provide a standard signallized intersection. The program has given all the details i.e., the number of phases of a signal, signal timings, sight distance specifications, details for channelizing islands etc. The layout drawn according to the results is shown in Fig. 4.2.

Regarding the performance characterestics, the average delay per vehicle is about 15.05 seconds, which is within the permissible limit of 25 seconds. The maximum queue length among the four legs is 4. Green time for that particular phase is 18 seconds. On average if 2.5seconds. is taken as the time required to cross the intersection, the number of vehicles that can cross during green period is 7, which is more than 4. Hence design is satisfactory.

4.8 Description of Problem - Three

Intersection is to be designed for the following data.

Intersection is situated on an arterial street of an Urban area.

Width of major road is 18mts.

Turning trafic is available only interms of PCU but not in detail.

4.9 Consultation Paradigm for Problem 3

What is the nature of area? Urban or Rural
Enter 1 for Urban area
Enter 2 for Rural area
1

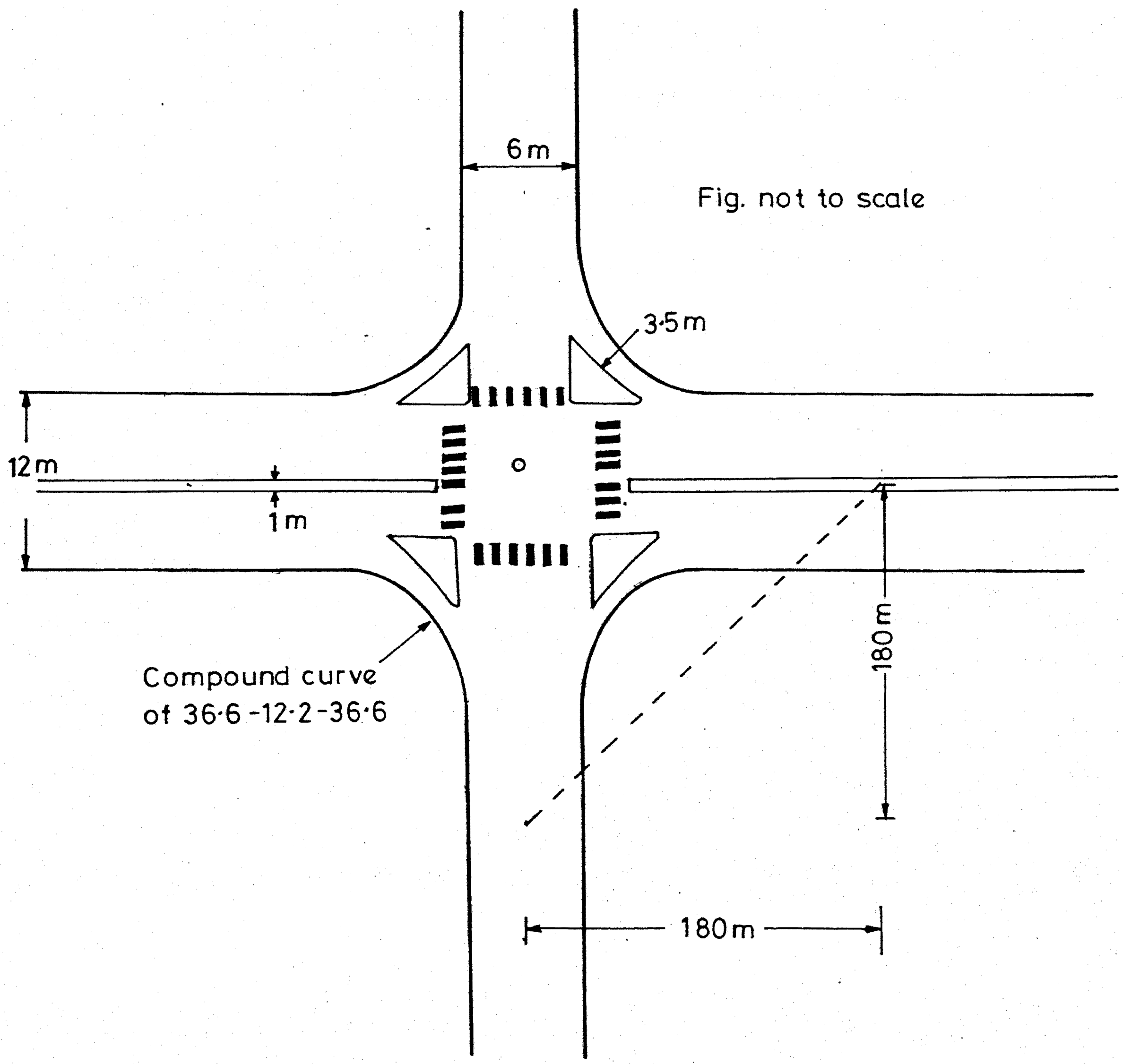

FIG. 4·2 SUGGESTED INTERSECTION LAYOUT FOR PROBLEM-TWO

```
Enter 1 if it is Arterial street
Enter 2 if it is Sub-arterial street
Enter 3 if it is Collection street
Enter 4 if it is Local street
1

Is it an existing intersection or new one (type old/new)
old
Then, enter number of legs of the intersection
4

You give numbers to all the four legs giving 3 and 4 to minor road
3 should be to the left of 1 and right of 2
4 should be to the right of 1 and left of 2
TAKE CARE IN NUMBERING THE LEGS
Now enter the peak hour traffic volume/hour
Can you enter all the turning traffic detailly for all types of
vehicles? (y/n)
n

In that case,
Enter total no. of vehicles in PCU going from leg 1 to leg 2
400

Enter total no. of vehicles in PCU going from leg 1 to leg 3
400

Enter total no. of vehicles in PCU going from leg 1 to leg 4
400

Enter total no. of vehicles in PCU going from leg 2 to leg 1
400

Enter total no. of vehicles in PCU going from leg 2 to leg 3
400

Enter total no. of vehicles in PCU going from leg 2 to leg 4
400

Enter total no. of vehicles in PCU going from leg 3 to leg 1
400

Enter total no. of vehicles in PCU going from leg 3 to leg 2
400

Enter total no. of vehicles in PCU going from leg 3 to leg 4
400

Enter total no. of vehicles in PCU going from leg 4 to leg 1
400

Enter total no. of vehicles in PCU going from leg 4 to leg 2
400

Enter total no. of vehicles in PCU going from leg 4 to leg 3
400
```

Enter the number of Pedestrians who crosses the intersection on all the ways
5ØØ

Sorry, I don't seem to provide a solution to this problem.
You may have to provide an INTERCHANGE.
For this case I can't give any more recommendations.

4.10 Discussion on the Result for Problem - Three

In this work, only four types of intersections are considered. They are namely simple intersection, signallized intersection, rotary type intersection, signallized rotary. Prolog tries to recommend any one of these four. When the entered traffic data given as input doesn't suit with the warrants of any one of the above four types, the program will fail and gives the above type of information.

CHAPTER V

SUMMARY, CONCLUSIONS, LIMITATIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 General

In this chapter, summary, conclusions and limitations of the present work and suggestions for the future work are outlined.

5.2 Summary of the Present Work

The entire work that was done in this thesis can be summarised in four phases as mentioned in this article. The first phase was literature review and in it the entire work that has been done on the present problem of intersection design was reviewed and design standards for various details were outlined. The second phase stands for establishing facts. Among the standards obtained in first phase, the necessary facts that are required to build expert system, such as warrants for signal, rotary and needs for signal, rotary etc., were picked out. The third and main phase was structuring the program. The facts that are necessary to solve the problem were written as rules in Turbo Prolog. The structure was made in such a manner that the program tries to prove only those rules which are necessary for that particularr type of intersection. In the final phase the program was tested for logical errors and found none. The suggestions given by program for two actual field problems were mentioned in the report.

5.3 Conclusions to the Present Work

From the above study one can understand that expert system

technique represent a new opportunity in computing. They open up avenues of application so far closed and allow new problems to be tackled. Although the ideas underpinning the technique are still in ferment, the techniques they employ have been in use for a decade or so. Neverthless, it was only recently that they achieved prominence in the public eye especially in the field of Transportation Engineering. By this day a little work has been done over them in this field. A lot of design problems can be handled in this field and a number of expert systems can be developed for a variety of situations.

Regarding the intersection, signallization is not feasible either for very high or too low traffic volumes. Decision has to be taken with consideration to the warrants. When signal is adopted, design of signal timings should be made accurately. Otherwise, long queues may be formed on the approaches leading to failure of intersection. When the intersection is of priority type, proper warning signs indicating the same should be provided. When a rotary is adopted, care should be encountered in designing carriageway details, which are the basis for capacity of the rotary. If unsufficient widths are provided for the carriageway in the rotaries locking up of rotary takes place frequently resulting in excessive delay to the vehicles. Another main precaution that is to be taken in case of rotaries is illumination during night times. Lack of proper illumination results severe fatalities causing loss of lives and property. Capacity of intersection mainly depends on widths of approach, turning movements, percentage of trucks and animal driven vehicles, pedestrians etc. When turning movements, trucks, animal driven

vehicles are more, intersectios should be modified to take care of them with special considerations such as widening the roads, increasing the radii of curves at intersection etc.

5.4 Limitations of the current work

In the current work different types of vehicles are converted into equivalent design vehicles (Passenger Car Units, PCU) with the following conversion factors.

Car, Tempo	1.Ø
Scooter, Motor cycle	Ø.5
Truck, Bus	3.Ø
Cycle	Ø.5
Rickshaw	1.5
Horse drawn vehicle	6.Ø
Bullock cart	8.Ø

With referrence to the above conversion factors, 1Ø bullock carts are equal to 8Ø passenger cars. But that is not so in the actual field. When traffic is too heavy one bullock cart may be equal to 8 passenger cars, but when traffic is very less one bullock cart is as good as one passenger car. Hence the conversion factors should be functions of actual traffic conditions and nature of the vehicles.

In the present work, the effect of a level crossing when it is in the close vicinity of intersection is not considered in either designing or in performance study of the intersection. Especially, when the intersection is of rotary type or signallized one with heavy volume, the effect of level crossing is very much

more. Sometimes one may have to even reallign the railway track.

5.5 Suggestions for Future Work

The present work can be extended to design interchanges, rail-road intersections etc. The program can be modified to make equivalent number of vehicles according to the actual traffic and geometric conditions instead of simply converting all types of vehicles in terms of PCU. The current work focussed on only one type of intersection that is suitable for the problem and in providing design details. Whereas one can design all the four types of intersections for the problem on hand and can analyze the effectiveness, feasibility of them to adopt according to the performance characterestics and other constraints such as costs, area of land required etc. As the graphics facility is also available in Prolog, one can extend the program to such a way that it gives the layout of suggested intersection also.

Apart from intersection design one can develop expert systems for many problems related to Transportation Engineering. Some problems of the above kind worthy of mentioning for expert system development are :

Route alignment design,

Speed limit decisions for various highways,

Geometric design,

Pavement design,

Pavement maintainance management,

Vehicle performance study on highways,

Urban and Regional transportation planning,

Transportation network analysis,

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